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The relationship of regional structural geology to the ore deposits in the southeastern Missouri mining district

Jack Alexander James

THE RELATIONSHIP OF REGIONAL STRUCTURAL GEOLOGY TO THE ORE DEPOSITS IN THE SOUTHEASTERN MISSOURI MINING DISTRICT

by

Jack Alexander James

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Doctor of Philosophy

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The undersigned, appointed by the Dean of the Graduate Faculty, have examined a thesis entitled

The Relationship of Regional Structural Geology to the Ore Deposits in the Southeastern Missouri Mining District

presented by Jack Alexander James

a candidate for the degree of Doctor of Philosophy

and hereby certify that in their opinion it is worthy of acceptance.

J. D. Forrester
W. A. Vines.

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This study has been consummated only through the combined efforts and cooperation of a large number of individuals and many organizations. An attempt to enumerate all those individuals who willingly and graciously helped is not feasible here, but their assistance is nonetheless valuable though not specifically mentioned. This study would not have been possible without the cooperation of the various mining companies within the district. The St. Joseph Lead Company, the largest operator in the district, furnished a large volume of information and data and gave the writer the opportunity to examine many ore bodies underground. Members of the Company's staff, particularly those individuals engaged in geologic work, freely discussed with the writer the interpretations of the relationships of the ore deposits. Similar cooperation was received from the St. Louis Smelting and Refining Division of the National Lead Company, the Park City Consolidated Mines Company, the Fredericktown Lead Company, and the staff members of these organizations. Other companies, which in the past carried on exploration programs in the district, made the results of their drilling programs available. Much of this type of information was furnished by the Minerva Oil Company — Mining Division, the American Metals Company, and the Midwest Mining Corporation.

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Doctor J. D. Forrester, Chairman of the Mining Department, furnished guidance, encouragement, and counsel in the course of the study. He made many helpful suggestions toward the interpretations and critically reviewed the report.

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CHAPTER I

INTRODUCTION

Introductory Statement

The lead deposits in the Southeastern Missouri mining district have been examined by numerous geologists and mining engineers since the original discovery about 1720. A list of the men who have reported on them includes some of the outstanding students of ore deposits.

The regional geology in the mining district either was unknown or only vaguely known when most of the early examinations were made, and the discussions of the structural geology are restricted in scope owing to the lack of detailed information. The reports based on these examinations, although excellent for their time, are incomplete in view of the information now available.

The major portion of the area was not mapped geologically until long after most of the reports appeared in print; hence, basic geologic data were not available to the earlier authors. The latest report of near district-wide scope was published in 1908 when detailed areal geology was available in only three quadrangles. Later stratigraphic information necessitated a revision of the areal geology in two of the three quadrangles, and they have been remapped since 1943. Maps of detailed areal geology are available now in all of the 20 quadrangles included in the mining district. Thirteen of them are

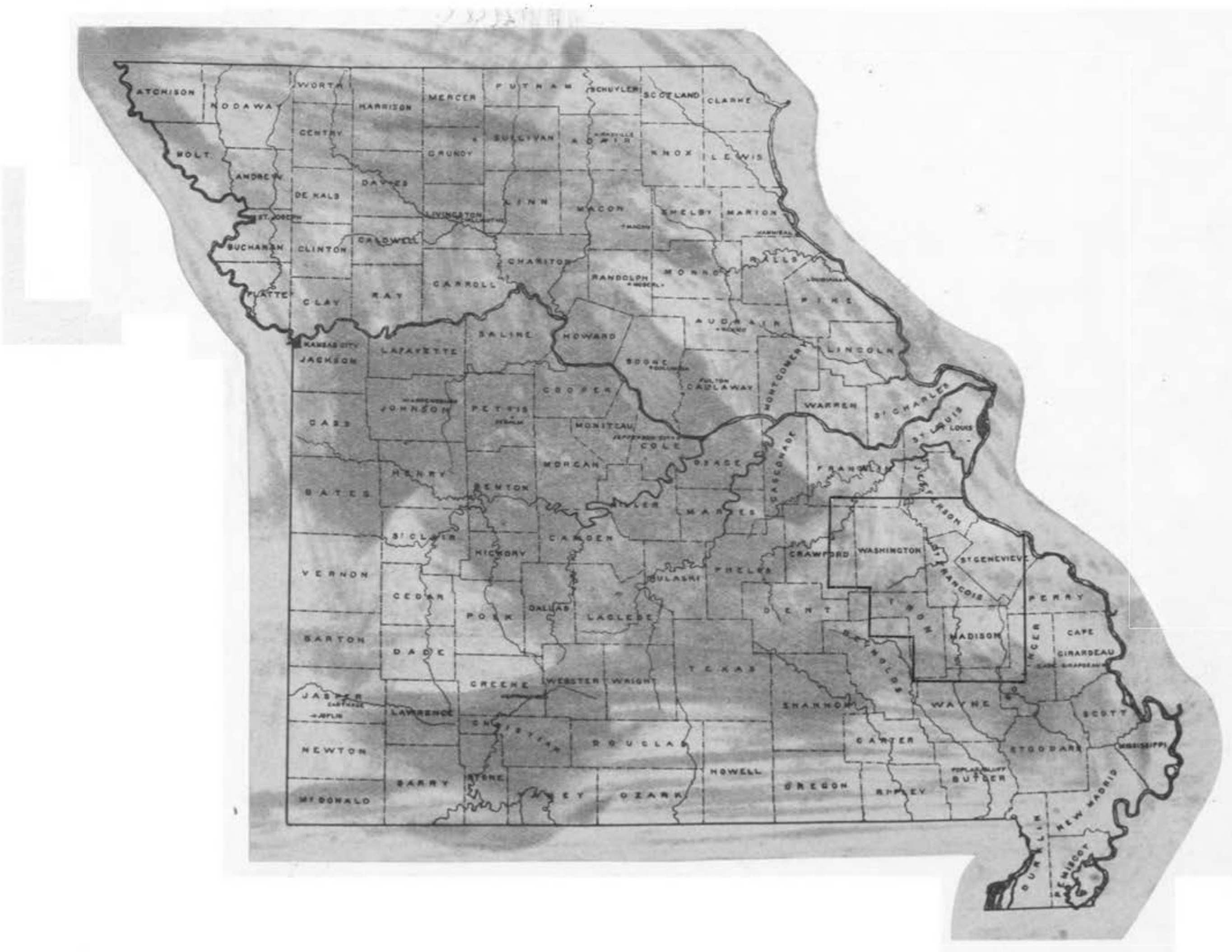

FIGURE 1

Index Map of the Southeastern Missouri Mining District mapped completely, and the other seven are mapped partially. The information gained from the geologic mapping has led to an understanding of the stratigraphy which is fundamental for a determination of the structures.

Exploration and development work in the past half century has enhanced the knowledge of stratigraphy and structure. The information accumulated particularly over the past 30 years restricts the usefulness of earlier reports. These reports are valuable chiefly for their description of properties now mined out, abandoned, or otherwise inaccessible, and for their historical reviews.

Discussions of the structural geology in the mining district have been neglected in the published literature. This neglect is understandable in view of the paucity of information available to the authors. The neglect may be due, in part, to the controversy about the source of the mineralizing solutions which deposited the lead ores. This controversy focused the attention of many investigators upon mineralogy and paragenesis, and the zoning of the minerals to the exclusion of district-wide structural relations of the ore deposits.

An earlier report was not feasible before the last decade because of the lack of sufficient information about the district-wide stratigraphy and structural geology.

Location of the Mining District

The geographical location of the area included on the maps accompanying this report and referred to as the Southeastern Missouri mining district is shown in Figure 1.

The boundary line extends southward from the Mississippi River along the 90°00' west longitude line to the 37°15' north latitude line, then westward along the 37°15' north latitude line to the 90°45' west longitude line, then northward along the 90°45' west longitude line to the 37°30' north latitude line, then westward along the 37°30' north latitude line to the 91°00' west longitude line, then northward along the 91°00' west longitude line to the 37°45' north latitude line, then westward along the 37°45' north latitude line to the 91°15' west longitude line, then northward along the 91°15' west longitude line to the 38°15' north latitude line, then eastward along the 38°15' north latitude line to the Mississippi River, then southeastward along the Mississippi River to the original point.

The mining district includes all of St. Francois and Madison counties and a part of Washington, Crawford, Franklin, Jefferson, Ste. Genevieve, Perry, Bollinger, Wayne, Iron, and Reynolds counties.

The center of the mining district is 60 miles south of the city of St. Louis, Missouri.

The quadrangles included in the map area, either entirely or in part, are the following:

Sullivan	15 minute sheet	scale 1:62,500
Richwoods	15 minute sheet	scale 1:62,500
Fletcher	7½ minute sheet	scale 1:24,000
Tiff	7½ minute sheet	scale 1:24,000
De Soto, NE	7½ minute sheet	scale 1:24,000
De Soto, SE	7½ minute sheet	scale 1:24,000
Crystal City	15 minute sheet	scale 1:62,500
Renault	15 minute sheet	scale 1:62,500
Berryman	15 minute sheet	scale 1:62,500
Potosi	15 minute sheet	scale 1:62,500
Bonne Terre	15 minute sheet	scale 1:62,500

Farmington	15 minute sheet	scale 1:62,500
Weingarten	15 minute sheet	scale 1:62,500
Edgehill	15 minute sheet	scale 1:62,500
Ironton	15 minute sheet	scale 1:62,500
Fredericktown	15 minute sheet	scale 1:62,500
Higdon	15 minute sheet	scale 1:62,500
Des Arc	15 minute sheet	scale 1:62,500
Coldwater	15 minute sheet	scale 1:62,500
Marquand	15 minute sheet	scale 1:62,500

The position of these quadrangles is shown in Figure 32.

The map area is so delineated because the majority of the lead mines and prospects are within these boundaries, because the major structural features of this portion of Missouri are within these limits, and because the structural pattern is revealed by the detailed geologic mapping within these boundaries. It may be suggested that the Southeastern Missouri mining district should be extended in all directions to include a few outlying prospects, especially northwestward to include mines and prospects in Franklin County. The Franklin County area has not necessarily been omitted from the mining district, but excluded only from the map. This area and other outlying areas were considered in the interpretations, but their inclusion on the map would not alter the regional pattern.

Previous Work

The accumulation of information concerning the structural geology in the Southeastern Missouri mining district is revealed by various publications. The sequence of accumulation and extent of this knowledge becomes evident by a study of the literature.

Published reference to the lead deposits dates back to 1804.[1]

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1 Moses Austin, "Description of the Lead Mines in Upper Louisiana," extracted from the "American State Papers," Public Lands, Vol. 1. Communicated to Congress November 8, 1804. P. 188. Report of the Geological Survey of the State of Missouri including Field Work of 1873-1874, 1:686-694, 1874.

Austin described the nature of the ore at 10 mines and gave their location in a report to Congress.

Schoolcraft[2,3] published on the lead mines.

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2 Henry A. Schoolcraft, A View of the Lead Mines of Missouri, Including Some Observations on the Mineralogy, Geology, Geography, Antiquities, Soil, Climate, Population, and Productions of Missouri and Arkansas and Other Sections of the Western Country (New York: 1819).

3 ______, Journal of a Tour into the Interior of Missouri, Arkansas, and from Potosi or Mine a Burton in Missouri Territory, in a Southwest Direction towards the Rocky Mountains. Performed in the Years, 1818 and 1819 (London: 1821).

The lead ores of Missouri were discussed by Troost and Lesuer.[4]

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4 Gerald Troost, and Charles A. Lesuer, "Calmine in Missouri; Lead Ores in Missouri," American Journal of Science, 1st ser., 12:376-380, 1827.

Mine La Motte was given specific mention by Featherstonhaugh.[5]

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5 G. W. Featherstonhaugh, Geological Report of the Examination Made in 1834, of the Elevated Country Between the Missouri and Red Rivers (Washington: 1835).

He described the quarrying operation for the extraction of lead ore at this property.

Hodge[6] pointed out the association of fracturing and lead

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6 J. T. Hodge, "On the Wisconsin and Missouri Lead Region," American Journal of Science, 1st ser., 43:35-72, 1842.

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mineralization. He illustrated the position of the copper ore at the Philadelphia Mine (Mine La Motte Copper Mine) in relation to the sedimentary-igneous rock contact. However, this relative position was not proposed for the lead deposits.

Litton[7] compiled available information concerning many lead

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7 A. Litton, "A Preliminary Report on Some of the Principal Mines in Franklin, Jefferson, Washington, St. Francois, and Madison Counties, Missouri," Geological Survey of Missouri, Reports I and II, Part 2, 1855.

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deposits, but he made no effort to discuss the regional structural geology in the mining district. Local stratigraphy and structure were mentioned in connection with the description of the mode of occurrence of the mineralization at the individual mines. Litton's work expanded knowledge of the association of fracturing and mineralization and established the presence of this association at several mines.

In 1873, Shumard[8] reported on the economic geology of Crawford,

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8 B. F. Shumard, "Crawford County, Perry County, Ste. Genevieve County, Jefferson County," Reports on the Geological Survey of the State of Missouri 1855-1871. 1873. Pp. 243-257; 277-289; 290-303; 304-313.

Perry, Ste. Genevieve, and Jefferson counties. This report contains the first attempt to establish the stratigraphic succession in the mining district. Brief descriptions of the mines in these counties are included, but there is no discussion of the structural geology.

Additional information about the stratigraphy in the mining district is gained as the result of the work by Broadhead[9] in Madison County. Remarks on structural geology are limited to the unconformable relations of the basement rock with the overlying sediments. The first geologic map of an area within the mining district accompanies this report.

9 G. C. Broadhead, "Madison County," Report of the Geological Survey of the State of Missouri including Field Work of 1873-1874, 1:342-370, 1874.

The paper by Gage[10] on the lead deposits in southeastern Missouri embodies the first discussion of the regional geology in the mining district. The limited extent of the knowledge at that time is indicated by Gage's reference to a disturbance near Mine La Motte. He wrote that "At this point I found the first and only disturbance that I have observed in this district."[11]

10 J. R. Gage, "Lead Mines — Southeast Missouri," Report of the Geological Survey of the State of Missouri including Field Work of 1873-1874, 1:601-637, 1874.

11 Ibid., p. 627.

Broadhead[12] reiterated the description of the occurrence of the lead mineralization previously described by Litton.

12 G. C. Broadhead, "The Southeast Missouri Lead District," Transactions of the American Institute of Mining Engineers, 5:100-107, 1876.

Mills[13] made a detailed examination of the Mine La Motte estate

13 J. E. Mills, Geological Report on the Mine La Motte Estate, the Property of Hon. Rowland Hazard, Situated in Madison County, Missouri (New York: G. W. and C. B. Colton and Company, 1877).

and reported the results of this examination to the owner, Rowland Hazard. The stratigraphy was studied in detail and the structural attitude of the sediments along the flanks of the pre-Cambrian knobs and ridges and several faults were recognized. Mills' report contains the second geologic map of an area within the mining district; the Mine La Motte estate lies within the area covered by Broadhead's geologic map.

Jenny[14] delineated the Ozark uplift and assigned the dynamic

14 W. P. Jenny, "The Lead and Zinc Deposits of the Mississippi Valley," Transactions of the American Institute of Mining Engineers, 22:171-225, 1894.

disturbances to two distinct periods. He announced the general law that:

> ...all workable deposits of ore occur in direct association with faulting fissures traversing the strata, and with zones or beds of crushed and brecciated rock, produced by movements of disturbance. The undisturbed rocks are everywhere barren of ore.

The limited extent of the information concerning the regional structural geology in the Southeastern Missouri mining district is displayed by Jenny's reference to the faulting at Mine La Motte as the largest faulting in the region.

Winslow[15] prepared a comprehensive descriptive report on the

15 Arthur Winslow, Lead and Zinc Deposits, Missouri Geological Survey, 6 and 7: 1894.

mines. An increase in the extent of knowledge of the regional structural geology is evident from Winslow's mention of faulting near Mine La Motte, near Valle's Mine, in association with the mines in Franklin County, and from his reference to the anticlinal feature now identified as the Farmington anticline. His descriptions help to crystallize the concept of the position of the ore deposits in relation to the irregular configuration of the pre-Cambrian basement rock. The ore bearing beds-basement rock relation illustrated by Hodge in 1842 for the copper ore at the Philadelphia Mine (Mine La Motte Copper Mine) is shown to apply to some of the lead deposits.

Additional areal geologic maps of areas within the mining district appeared in 1896 accompanying reports on the Iron Mountain Sheet[16] and the Mine La Motte Sheet.[17] The sedimentary strata are

16 Arthur Winslow and others, "A Report on the Iron Mountain Sheet, including Portions of Iron, St. Francois, and Madison Counties," Missouri Geological Survey, 9:Report 3, 1894.

17 C. R. Keyes, "A Report on the Mine La Motte Sheet, including Portions of Madison, St. Francois, and Ste. Genevieve Counties," Missouri Geological Survey, 9:Report 4, 1895.

undifferentiated on the geologic map of the Iron Mountain Sheet. The discussion of the structural geology is restricted to the dip of the sediments away from the topographic highs on the pre-Cambrian erosional surface. On the geologic map of the Mine La Motte Sheet, the sedimentary strata are differentiated into the La Motte, Fredericktown, and Le Sueur formations. The discussion of the structural geology includes remarks concerning the dip of the sediments on the flanks of the pre-Cambrian topographic highs, the unconformable relation between the sediments and the igneous rock, the jointing, and the faulting.

Winslow[18] gave a concise discussion of the structure, but no

18 Arthur Winslow, "The Disseminated Lead Ores of Southeastern Missouri," United States Geological Survey, Bulletin 132, 1896.

information was presented in addition to that already available in earlier publications.

Bain's reference to the mining district is prefaced by the remark that "Because of time limitations it (this district) was very little studied in the course of the present work, and accordingly no attempt will be made to discuss it."[19]

19 H. F. Bain, "Preliminary Report on the Lead and Zinc Deposits of the Ozark Region," Annual Reports of the Department of the Interior, Twenty-Second Annual Report of the United States Geological Survey, 2:23-228, 1901.

Perhaps the most intensive study of near district-wide scope is that by Buckley.[20] A detailed areal geologic map of the Bonne Terre

20 E. R. Buckley, Geology of the Disseminated Lead Deposits of St. Francois and Washington Counties, Missouri Bureau of Geology and Mines, 2d ser., 9:Parts 1 and 2, 1908.

quadrangle is included in his report. The delineation of the formations on this map is essentially the same as that in use today, except that the former Potosi is now divided into the Potosi and Eminence formations. Most of the large, and many of the small, structural features are shown on Buckley's map. Several zones of faulting are mapped, and the structures in the individual mines are described in considerable detail.

In 1911, Buckley[21] again briefly described the geologic

21 E. R. Buckley, Lead and Zinc Deposits of the Ozark Region (H. Foster Bain, editor, Types of Ore Deposits, San Francisco: Mining and Scientific Press, London: The Mining Magazine, 1911) pp. 106-107.

structures in the mining district.

The interpretation Buckley placed upon the origin of the lead deposits precipitated a discussion in the literature about the origin of these deposits. Following Buckley's report either corroborative or argumentative opinions on the origin of these deposits were expressed by Cantwell,[22] Nason,[23] Pirsson,[24] Spurr,[25] Buehler,[26]

22 H. J. Cantwell, "The Disseminated Lead District of Southeast Missouri," Engineering and Mining Journal, 97:287-290, 1914.

23 F. L. Nason, "The Disseminated Lead District of Southeast Missouri," Engineering and Mining Journal, 97:1158-1159, 1914.

24 L. V. Pirsson, "Origin of Certain Ore Deposits," Economic Geology, 10:180-186, 1915.

25 J. E. Spurr, "The Origin of Certain Lead Deposits," Economic Geology, 10:472-475, 1915.

26 H. A. Buehler, "Geology and Mineral Deposits of the Ozark Region," Transactions of the American Institute of Mining Engineers, 58:398-408, 1918.

Emmons,[27] and Tarr.[28] These opinions add little to the knowledge of

27 W. H. Emmons, "The Origin of the Deposits of Sulphide Ores of the Mississippi Valley," Economic Geology, 24:221-271, 1929.

28 W. A. Tarr, "Origin of the Southeast Missouri Lead Deposits," Economic Geology, 31:712-754 and 832-866, 1936.

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the district-wide structural geology.

Knowledge of the stratigraphy and the structural geology has grown since 1908 largely as the result of geologic investigations in individual areas. The reports of these investigations either were delayed in reaching publication or are not published.

A report on Ste. Genevieve County,[29] including an areal geo-

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29 S. Weller and S. St. Clair, Geology of Ste. Genevieve County, Missouri, Missouri Bureau of Geology and Mines, 2d ser., 22: 1928.

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logic map, was published in 1928. It includes descriptions of the basement rock and formations ranging in age from Cambrian to Mississippian. The geologic map shows the Ste. Genevieve fault zone in considerable detail and the extent of the Farmington anticline.

The dip of the sediments on the flanks of the topographic highs on the pre-Cambrian erosional surface was described as initial dip by Bridge and Dake.[30]

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30 Josiah Bridge and C. L. Dake, "Initial Dip Peripheral to Resurrected Hills," Missouri Bureau of Geology and Mines, 55th Biennial Report of the State Geologist, appendix 1, 1929. Pp. 93-99.

In a report on the Potosi and Edgehill quadrangles which appeared in 1930,[31] the Upper Cambrian and some Ordovician formations

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31 C. L. Dake, The Geology of the Potosi and Edgehill Quadrangles, Missouri Bureau of Geology and Mines, 2d ser., 23: 1930.

are described in detail. The geologic map shows three zones of faulting.

A paper containing a summary and bibliography of the literature concerning the lead and zinc deposits in the Mississippi Valley region includes several sections on the Southeastern Missouri mining district.[32]

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32 E. S. Bastin, et al., Contributions to a Knowledge of the Lead and Zinc Deposits of the Mississippi Valley Region, Geological Society of America, Special Paper No. 24, 1939.

A thesis on the Ozark Lead Mine[33] points out the structural

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33 E. L. Ohle, Jr., "The Geology of the Ozark Lead Mine," (unpublished Master's thesis, Washington University, St. Louis, 1940).

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relations of the ore body, especially with reference to the pre-Cambrian topographic highs in the vicinity of the mine.

The Fredericktown quadrangle was mapped geologically in 1943.[34]

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34 Dan R. Stewart and Kenneth Aid, "Preliminary Geologic Map of the Fredericktown District," (unpublished map, Missouri Geological Survey and Water Resources, Rolla, 1943).

Approximately 16 square miles of detailed areal geologic mapping in the vicinity of Annapolis, Iron County, was completed in 1946.[35]

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35 A. L. Kidwell, "Geologic Map of the Annapolis Area," (unpublished map, Missouri Geological Survey and Water Resources, Rolla, 1946).

Part of the Berryman quadrangle was mapped in 1948,[36] 1949,[37] 36 Jack A. James, "Geology of the Berryman Area, Washington County," (unpublished Master's thesis, Missouri School of Mines and Metallurgy, Rolla, 1948).

37 George John Degenfelder, "Geology of the Southwest Portion of the Berryman Quadrangle, Missouri," (unpublished Master's thesis, State University of Iowa, Iowa City, 1950).

and 1950.[38]

38 John W. Erickson, "Geologic Map of Part of the Berryman Quadrangle," (unpublished map, Missouri Geological Survey and Water Resources, Rolla, 1950).

The Vineland (De Soto, SE) and Tiff quadrangles were mapped in 1949.[39]

39 E. J. Parizek, "Geology of the Vineland and Tiff Quadrangles in Southeastern Missouri," (unpublished Doctor's dissertation, State University of Iowa, Iowa City, 1949).

Additional geologic mapping was done in the field season of 1950 in the Sullivan,[40] Richwoods,[41] Ironton,[42] and Coldwater[43]

40 William L. Petrie, "Geology of the Southeast Portion of the Sullivan Quadrangle, Missouri," (unpublished Master's thesis, State University of Iowa, Iowa City, 1951).

41 Ansel M. Gooding, "Geologic Map of the Southwest Portion of the Richwoods Quadrangle," (unpublished map, Missouri Geological Survey and Water Resources, Rolla, 1950).

42 Edwin D. Goebel, "Geologic Map of the Ironton Quadrangle," (unpublished map, Missouri Geological Survey and Water Resources, Rolla, 1950).

43 Robert H. Dott, Jr., and Alan D. Curtis, "The Geology of the Northern Half of the Coldwater Quadrangle, Madison County, Missouri," (unpublished Master's thesis, University of Michigan, Ann Arbor, 1951).

quadrangles.

The bibliography of this report is not intended to be complete, but to include only the works to which reference is made. Other reports make reference to the mining district, but say little or nothing about the structural geology, and these have been omitted from the bibliography.

Purpose and Scope

The paucity of information in the published literature concerning the regional structural geology and its relation to the ore deposits in the Southeastern Missouri mining district demonstrates the need for this study. A review of the literature, manuscript reports, theses, and field maps indicates that detailed geologic mapping is sufficient, and that descriptions of rock formations are distributed adequately to furnish the basic data for a study of the regional structural geology. Preliminary work has substantiated these indications, and it suggests that this study will contribute to the interpretation of these ore deposits, to the structural history of the Ozark uplift region, to prospecting and exploration, to development of ore bodies, and to an estimate of the potential of the Southeastern Missouri mining district.

One of the underlying reasons for the choice of regional structural geology as an initial study is aptly expressed by Longwell. He wrote that "...the real significance of local geology sometimes appears only when viewed within a larger framework."[44] The present

44 C. R. Longwell, "Tectonic Theory Viewed from the Basin Ranges," Bulletin of the Geological Society of America, 61:413, 1950.

study was undertaken to ascertain the structural controls which are effective in localizing the Southeastern Missouri mining district and in localizing the areas of ore deposits within the mining district, and to ascertain the effect of the structural controls upon the mode of occurrence of the ore bodies. It is hoped that this work will aid in prospecting and exploring for and developing new ore deposits. The complexity of the problem and the time available limited the scope of this investigation to a study of the regional structural geology and its relationship to the localization and mode of occurrence of ore deposits. Detailed stratigraphic and structural studies of individual ore bodies are considered only so far as necessary to formulate the regional controls. Other phases of a comprehensive study such as mineralogy, paragenesis, origin, and detailed structures of individual ore bodies are beyond the scope of this study.

Present Work

The writer has spent three years on this work while a member of the staff of the Missouri Geological Survey and Water Resources. Field work was done intermittently throughout this period, but chiefly during the summer field seasons of 1948, 1949, and 1950. Field work consisted mostly of detailed examinations of the structural features, stratigraphic studies of a regional nature, and examinations of mines and prospects. Samples from drillholes were examined in the field and in the laboratory. Thousands of samples representing several hundred drillholes have been examined and, in addition, records of hundreds of drillholes have been critically reviewed.

CHAPTER II

REGIONAL SETTING OF THE MINING DISTRICT

STRATIGRAPHIC

The sedimentary formations are a part of extensive sedimentation in the mid-continent region of the United States. Some aspects of the formations are dependent upon broader controls of sedimentation than were effective within the mining district alone, but other aspects can be related to local controls of sedimentation.

The rock succession is a basement of pre-Cambrian extrusive and intrusive igneous rocks overlain unconformably by a sedimentary series ranging in age from Upper Cambrian to Pennsylvanian. The base upon which the pre-Cambrian extrusives rest is unknown. The basement rock was subjected to a prolonged period of erosion and valleys more than 1500 feet deep were carved in this surface. The sedimentary series was deposited upon this rugged erosional surface; consequently, the mineralized sediments are separated from the basement rock by a profound unconformity.

The igneous rocks are classified by Robertson.[45] These rocks are not discussed in this report because they will be fully described in the report by Robertson and because all the known basement igneous rocks are of pre-Cambrian age.

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45 F. S. Robertson, Manuscript in preparation for a report on the igneous rocks of Missouri, 1950.

The sedimentary formations have been described adequately by various authors.[46] Although mineralization has been found in sufficient quantity to encourage exploration and, in some instances, mining in other than Upper Cambrian strata, the most extensive deposits are restricted to the Bonneterre formation of Upper Cambrian age. Because of the importance of the Bonneterre as the host rock, this formation and contiguous formations were studied more carefully and are discussed more fully in this report than other strata represented in the mining district.

46 See bibliography and refer to C. L. Dake, 1930; Josiah Bridge, 1930; S. Weller and S. St. Clair, 1928; E. R. Buckley, 1908; and Arthur Winslow, 1894.

The following discussion is a resumé of the salient features of these formations with regional manifestations as observed and interpreted by the writer.

Formations Discussed

Age	Group	Formation	Thickness in feet
		?unconformity?	
Upper Cambrian	Elvins	Derby-Doerun	0-110
		Davis	0-180
		Bonneterre	0-600
		Lamotte	0-450
		unconformity	

Lamotte Formation

The Lamotte formation was named by Winslow[47] from exposures

47 Arthur Winslow, Lead and Zinc Deposits, Missouri Geological Survey, 6 and 7:347, 1894.

in the vicinity of Mine La Motte, St. Francois County. It was defined originally as a basal sandstone overlying the "Archean" crystallines and underlying the limestone beds in which the ore is found.

Most of the areas where the Lamotte crops out in the Southeastern Missouri mining district are northeast of the St. Francois Mountains. The largest area of outcrop is in Ste. Genevieve and St. Francois counties where the formation is brought to the surface by the Farmington anticline. Another large area of outcrop in southern St. Francois and northern Madison counties is the result of faulting which has differentially raised the exposed central pre-Cambrian igneous mass of the St. Francois Mountains and permitted erosion to uncover the Lamotte. A smaller area, the result of similar conditions of faulting, is exposed in southeastern Washington County. Other isolated outcrops are where the formation rises along the slopes on the basement rock surface to the level of the present erosional surface.

The thickness of the formation is variable owing to its deposition on an erosional surface. The greatest known thickness is 451 feet which was encountered in a drillhole in the vicinity of Farmington, St. Francois County. The Lamotte does not cover many of the topographic highs on the pre-Cambrian erosional surface that are buried by younger strata which overlap the Lamotte. As a result of this overlap, known thicknesses range from zero to the 451 feet indicated above, and it is probable that even greater thicknesses exist. At Fredericktown, Madison County, the Lamotte is 150 feet thick; at Bonne Terre, St. Francois County, it is 239 feet thick. Near Black, Reynolds County, 223 feet of sandstone was drilled without reaching the base of the formation; near Palmer, Washington County, a maximum of 91 feet of Lamotte was cut without penetrating the formation. In other drillholes the total thickness was less than 91 feet. Five miles southeast of Sullivan, Franklin County, 310 feet of sandstone was drilled before the basement rock was reached.

Data from several drillholes in southwestern Madison County, northeastern Iron County, southwestern St. Francois County, and northeastern Reynolds County indicate that the Lamotte is absent at some places, but the drilling is not adequate to define the buried topography of the basement rock surface. Although samples from some drillholes show the Bonneterre lying directly on the basement rock, several drillholes in southern Iron County, in T. 30 N., Rs. 2 and 3 E., and in T. 31 N., R. 3 E., encountered the Lamotte in topographic lows of the pre-Cambrian surface. However, the formation was not deposited in a sizeable elongated area centering southeast of Ironton, Iron County. The evidence for non-deposition is treated in the discussions of the Bonneterre and the unconformity at the base of the sedimentary series. The Lamotte is absent in adjacent areas where the basement rock projected above the Lamotte sea. Consequently, the distribution and thickness of the Lamotte formation depend, in part, upon the configuration of the erosional surface upon which it

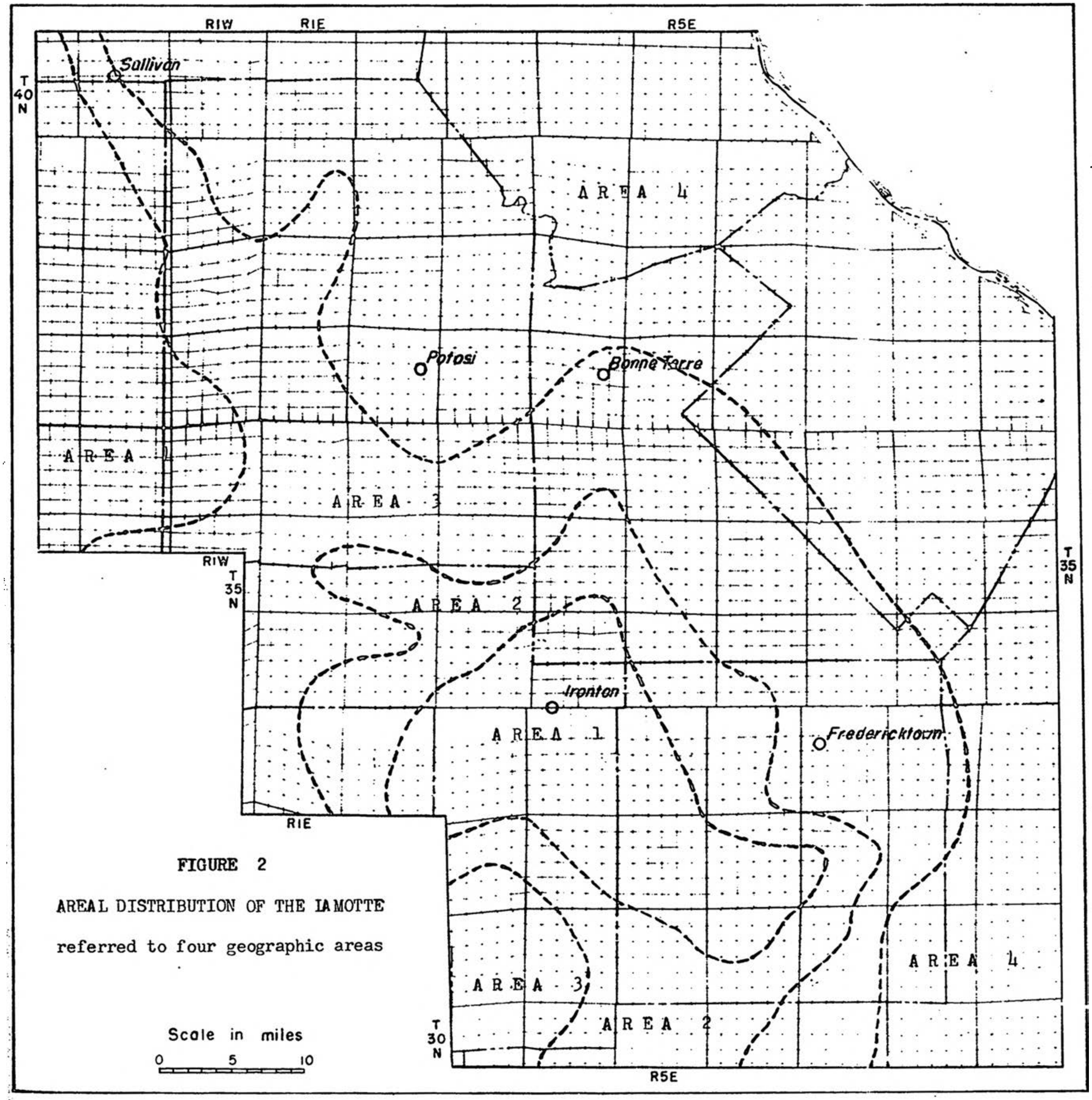


FIGURE 2

AREAL DISTRIBUTION OF THE LAMOTTE

referred to four geographic areas

was deposited.

The areal distribution of the Lamotte can be referred to four geographic areas. The limit of each area is indefinite owing to lack of adequate subsurface control, but the general pattern is suggested by the existing information.

Area 1 is a central area, 25-30 miles long and 10-12 miles wide, elongated in a northwest direction, and centering a few miles southeast of Ironton, Iron County. The Lamotte is absent within this area because of non-deposition.

Area 2 is an area surrounding (1) and with essentially parallel boundaries. This area includes the western half of Madison County, the southwest quarter of St. Francois County, a small portion of southeastern Washington and northern Wayne counties, the northeast corner of Reynolds County and the northeastern portion of Iron County. The Lamotte is absent over most of this area, although it is present in the lower portion of the buried valley system on the pre-Cambrian surface. The formation is restricted in this area perhaps because the quantity of deposited material and the depth of the sea was not sufficient to fill the valley system and spread the sediments across even the lower dividing ridges.

Area 3 is an area enveloping (1) and (2), including most of Madison, St. Francois, and Iron counties, and part of Washington, Crawford, Wayne, and Reynolds counties. In addition, an irregular projection extends into Franklin County in the vicinity of Sullivan. Other projections probably exist. The Lamotte is present over most of this area, but it is absent over the higher topographic features on the pre-Cambrian erosional surface. The depth of the sea and the quantity of sediments deposited nearly filled the valley system. The formation spread across all but the highest dividing ridges between the buried valleys.

Area 4 lies beyond the limits of (3). The Lamotte may be expected to be present nearly everywhere in this area. The basement rock is completely blanketed by the Lamotte formation.

The areal distribution of the formation reflects the presence of an elongated highland during the time of Lamotte deposition at almost the same position as that occupied by the St. Francois Mountains.

The Lamotte is predominantly a quartz sandstone which is locally arkosic. Where it is typically developed, the bulk of the formation consists of medium-sized, clear to frosted, rounded to angular sand grains which are cemented with either dolomite or silica. The color of the sandstone varies from nearly white through shades of yellowish and brown to red, depending upon the amount of iron present.

Silty shale, shale, dolomite, and pebbles, cobbles, and boulders of igneous rock are other constituents of the Lamotte. Silty shale forms individual layers a few inches thick or an aggregate of platy layers as much as five feet thick. It occurs in the basal portion of the formation near the pinch-out against a topographic high feature on the pre-Cambrian erosional surface. It is predominantly red and reddish purple. Fragments of the basement rock are disseminated through the shale beds.

In southeastern Washington County, in sec. 7, T. 35 N., R. 3 E., the basal beds of the formation consist of a conglomerate of weathered felsite boulders as much as one foot in diameter which are embedded in a matrix that contains clay.[48] Dake believed the clay

48 C. L. Dake, The Geology of the Potosi and Edgehill Quadrangles, Missouri Bureau of Geology and Mines, 2d ser., 23:49, 1930.

was reworked pre-Cambrian soil. Field relations of this exposure indicate that it is basal Lamotte and near to the pinch-out of the formation against a pre-Cambrian topographic high. Less than 500 feet east the basement rock rises to an altitude 100 feet higher than the Lamotte. An excellent exposure of silty shale in the Lamotte is situated along Highway 70, six miles west of Fredericktown, Madison County, in sec. 5, T. 33 N., R. 6 E., on both sides of Piney Creek, where it aggregates five feet in thickness. The formation is preserved here in an embayment of sediments bordered on three sides by basement rock outcrops. Stewart[49] cites another locality of silty

49 Dan R. Stewart, et al., "Geology of the Fredericktown Quadrangle," (unpublished manuscript, Missouri Geological Survey and Water Resources, Rolla, 1947).

shale beds in the NW$\frac{1}{4}$NW$\frac{1}{4}$SE$\frac{1}{4}$ sec. 4, T. 33 N., R. 6 E., along the north side of a private road. Four feet of silty shale beds outcrop at this locality. This exposure is basal Lamotte bordered on three sides by basement rock outcrops. Apparently, embayments or cove-like depressions, forming sheltered areas, were favorable for the accumulation of the fine clastic material. The position and characteristics of several silty shale exposures substantiates Dake's belief that the shale was derived from the soil and detrital material on the pre-Cambrian surface at the time of the Lamotte sea invasion.

Shale layers are present throughout the formation although they are more abundant in the upper portion, near the Lamotte-Bonneterre contact. The color varies and may be either brown, green, or dark gray.

Dolomite is present in the formation as cementing material in sandstone and as sandy dolomite beds. The beds of sandy dolomite occur in the upper portion and are as much as 10 feet thick. Near Avon, Ste. Genevieve County, a dolomite bed 9 to 10 feet thick occupies a position about 50 feet below the top of the formation.[50]

50 S. Weller and S. St. Clair, Geology of Ste. Genevieve County, Missouri, Missouri Bureau of Geology and Mines, 2d ser., 22:36, 1928.

Five feet of dolomite, 90 feet below the top of the formation, is shown in records of a drillhole in the vicinity of Farmington, St. Francois County. It is reported that at Bonne Terre, St. Francois County, five feet of dolomite occurs 29 feet below the top of the formation. Buckley[51] recorded that five miles west of Bismarck,

51 E. R. Buckley, Geology of the Disseminated Lead Deposits of St. Francois and Washington Counties, Missouri Bureau of Geology and Mines, 2d ser., 9:21, 1908.

Washington County, a dolomite bed six to eight feet thick is overlain by 16 feet or more of sandstone. Five miles southeast of Fredericktown, Madison County, sandy dolomite beds in the Lamotte are encountered in drillholes at various stratigraphic positions and as much as 60 feet below the top of the sandstone beds.

The uppermost beds of the Lamotte are dolomitic at some places although they are composed chiefly of sandstone. Remarks by Weller and St. Clair[52] concerning the dolomite in the formation give an idea

52 Weller and St. Clair, loc. cit.

of its irregular distribution.

> The dolomitic bed in the upper part of the Lamotte formation outcrops in a number of widely separated localities, and is probably a more or less continuous horizon. Near Avon, where it occurs about 50 feet from the top of the formation, it is yellowish in color, calcareous, and has a thickness of from nine to ten feet. In the SE$\frac{1}{4}$ sec. 19, T. 37 N., R. 6 E., this bed also

> occupies a position approximately 50 feet below the Bonneterre, and is associated with shale and quartzite. At other points it is somewhat nearer the top of the formation, and it may be only three or four feet thick. This layer probably corresponds to similar beds encountered in adjoining counties.

The erratic stratigraphic position of sandy dolomite beds and the character of the gradation of the Lamotte into the overlying Bonneterre suggest that these are lenses of sandy dolomite rather than a continuous bed.

Stratification in the Lamotte ranges from thin, almost platy beds to massive layers several feet thick. Cross-bedding is common and usually has a low inclination. The cross-bedding dips 10° W. at Buzzard Rock, cen. SE$\frac{1}{4}$NW$\frac{1}{4}$ sec. 26, T. 35 N., R. 5 E.

Intra-formational conglomerates are numerous and mostly local in extent. They consist of basement rock fragments in a sandstone matrix. These intra-formational conglomerates and arkosic beds may be mistaken for erosional breaks unless their true relation is recognized. The angularity and variation in size of the included fragments and the limited extent of the conglomerates can be related to nearby topographic high features on the pre-Cambrian erosional surface which are the source of the fragmental material.

The base of the formation, where exposed, is either conglomeratic or arkosic. The basement rock, in most instances granite, seems to have been too much decomposed and disintegrated in some localities to form a conglomerate. At other localities the basal conglomerate is well developed with boulder size fragments of the basement rock in a sandstone, or sandstone and shale matrix. The thickness of the conglomerate is variable.

The Lamotte is the basal sandstone of the sedimentary succession and rests unconformably upon the eroded surface of the basement rock. At many places the basal portion grades laterally and vertically from a quartz sandstone to a feldspathic sandstone into an arkose. Accompanying the increase in feldspar content, there is an increase in angular quartz fragments and in the size range of the particles. An exposure of the arkose is easily accessible along Highway 32 where it crosses the north fork of Jonca Creek in the N$\frac{1}{2}$ sec. 8, T. 36 N., R. 7 E., Ste. Genevieve County. The basal or residual arkose rests on granite in this locality. In other localities, the quartz sandstone grades into arkose where felsite is the basement rock.

The lateral gradation of the quartz sandstone into an arkose is evident from exposures in secs. 19, 20, 28, 29, and 30, T. 35 N., R. 4 E. The sandstone north of Iron Mountain (secs. 29 and 30) changes gradually into arkose further east where it is exposed on the north and south of a conglomerate composed of well rounded cobbles of the basement rock in a siliceous matrix. The type of rock varies from an arkose to a cobble conglomerate in a horizontal distance of 200 feet; although the conglomerate is not continuously exposed, arkose appears to grade into it. The lateral gradation of quartz sandstone to arkose is determined by tracing the continuity of the strata from an area of sandstone into an area of arkose. A similar gradation of the Bonneterre calcareous rock into arkose prevents an immediate identification of arkose as a Lamotte equivalent.

The Lamotte grades into the overlying Bonneterre, and this

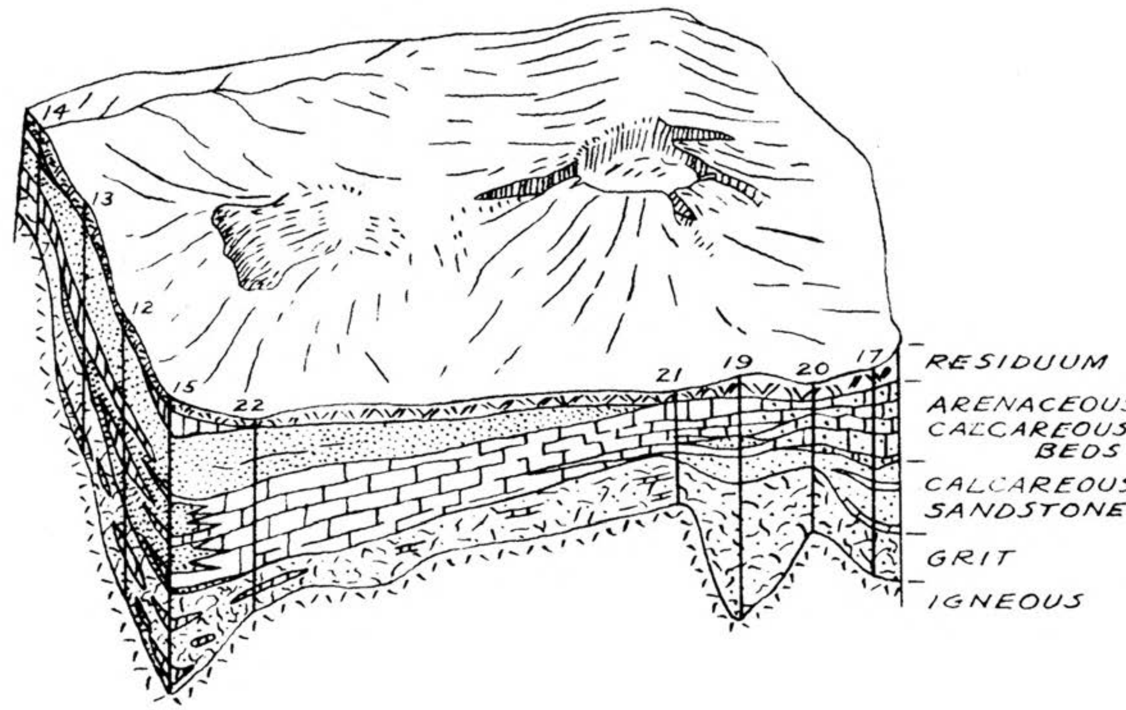


FIGURE 3

VARIABLE TYPES OF LITHOLOGY

IN THE VICINITY OF IRON MOUNTAIN, ST. FRANCOIS COUNTY

(AFTER WINSLOW)

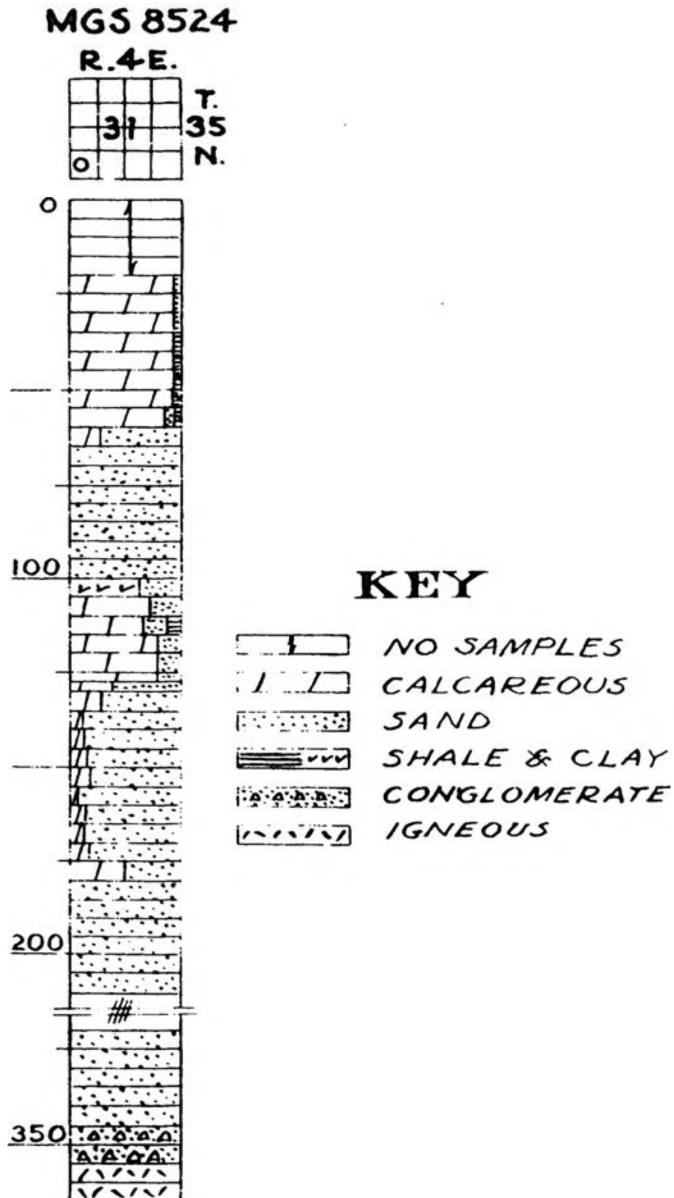


FIGURE 4

PREDOMINANT ARENACEOUS SEDIMENTS
OF THE LAMOTTE-BONNETERRE GRADATIONAL BEDS

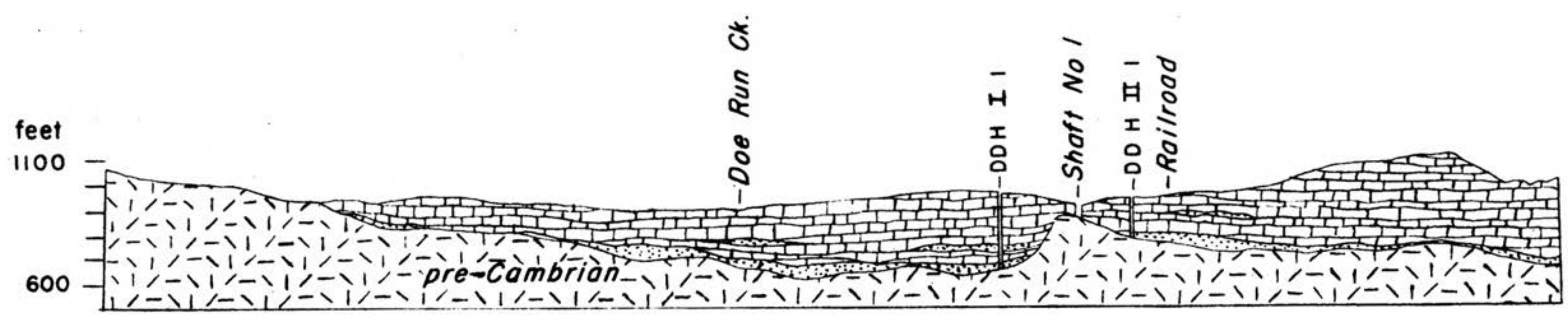


FIGURE 5

Diagrammatic section through the Doe Run Mines (After Winslow) gradation is variable. A transition zone of either inter-bedded sandstone and sandy dolomite, or only sandy dolomite beds occupies a position between sandstone below and non-sandy dolomite above. At some places the sandy dolomite predominates in this inter-bedded sequence, and at other places the sandstone predominates. The transition zone may be less than five feet or as much as 200 feet thick.

The variations in gradation from the Lamotte to the Bonneterre form a pattern which can be correlated with the areal distribution of the Lamotte (Fig. 2). Bordering the area of non-deposition of the Lamotte, the gradation is characterized by inter-bedded sandstone and sandy dolomite with sandstone predominant (see Fig. 3 and Fig. 4, depths 60 to 180 feet). Away from the border of the area of non-deposition, but still within geographical area (2), the same inter-bedded sequence prevails; however, the sandy dolomite becomes predominant in the sequence (see Fig. 5). Still farther from the area of non-deposition the change from sandstone to predominantly calcareous rock is more sharply defined. The succession is sandy dolomite above sandstone without the inter-bedded sequence in the transition zone. This succession prevails in the localities where the Lamotte contains sandy dolomite lenses. Progressively away from the area of non-deposition, deeper water conditions are indicated which would favor the formation of sandy dolomite lenses, particularly in the final stage of clastic deposition before predominantly calcareous deposition. When considering the nature of the transition from the clastic Lamotte to the calcareous Bonneterre and the erratic stratigraphic position of the sandy dolomite beds within the Lamotte, the possibility is strong that these sandy dolomite beds are lenses.

A succession of non-sandy dolomite beds overlying sandstone beds with a transition zone of sandy dolomite a few feet or a few inches thick is found in western Washington County and eastern Crawford County.

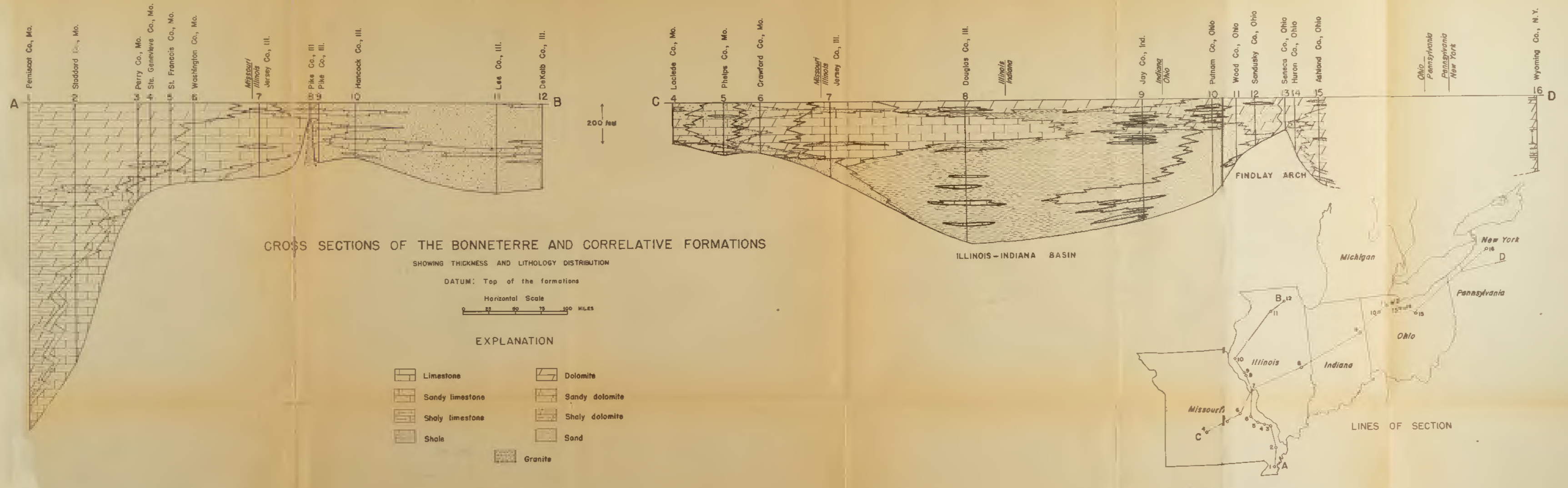
It is necessary to look to regions outside the mining district to establish a source for the Lamotte. Reasons for looking elsewhere for a source for the Lamotte clastics are the degree of rounding of the sand grains; the large volume of Lamotte and equivalent sandstones; the difficulty to explain the mechanics which would permit the accumulation of products of decomposition and disintegration from the pre-Cambrian mass while agents of erosion were vigorous enough to carve valleys more than 1500 feet deep in the resistant basement rock; and the restricted extent of locally derived material.

The age of the Lamotte formation is determined from its stratigraphic relation to the overlying Bonneterre formation rather than from direct paleontological evidence. Fossils collected from the Bonneterre designate the age of this formation as Upper Cambrian. The conformable stratigraphic relation of the Bonneterre to the underlying Lamotte suggests that it also is of Upper Cambrian age.

Bonneterre Formation

The Bonneterre formation was named by Nason[53] in 1901 from

53 F. L. Nason, "On the Presence of a Limestone Conglomerate in the Lead Region of St. Francois County, Missouri," American Journal of Science, 4th ser., 11:396, 1901.


Pemiscot Co., Mo.
Stoddard Co., Mo.
Perry Co., Mo.
Ste. Genevieve Co., Mo.
St. Francois Co., Mo.
Washington Co., Mo.
Missouri
Illinois
Jersey Co., Ill.
Pike Co., Ill.
Pike Co., Ill.
Hancock Co., Ill.
Lee Co., Ill.
DeKalb Co., Ill.
A
1
2
3
4
5
6
7
8
9
10
11
12
B
200 feet
Laclede Co., Mo.
Phelps Co., Mo.
Crawford Co., Mo.
Missouri
Illinois
Jersey Co., Ill.
Douglas Co., Ill.
Illinois
Indiana
Jay Co., Ind.
Indiana
Ohio
Putnam Co., Ohio
Wood Co., Ohio
Sandusky Co., Ohio
Seneca Co., Ohio
Huron Co., Ohio
Ashland Co., Ohio
Ohio
Pennsylvania
Pennsylvania
New York
Wyoming Co., N.Y.
C
4
5
6
7
8
9
10
11
12
13
14
15
16
D
FINDLAY ARCH
ILLINOIS – INDIANA BASIN
CROSS SECTIONS OF THE BONNETERRE AND CORRELATIVE FORMATIONS
SHOWING THICKNESS AND LITHOLOGY DISTRIBUTION
DATUM: Top of the formations
Horizontal Scale
0 25 50 75 100 MILES
EXPLANATION
Limestone
Dolomite
Sandy limestone
Sandy dolomite
Shaly limestone
Shaly dolomite
Shale
Sand
Granite
Michigan
New York
D
Pennsylvania
Ohio
Indiana
Illinois
Missouri
B
C
A
LINES OF SECTION

exposures in the vicinity of Bonne Terre, St. Francois County, Missouri. His delineation of the formation included strata which, at present, are included in the Davis formation. The currently accepted definition of the Bonneterre formation was made by Buckley[54] in 1908.

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54 Buckley, op. cit., pp. 26-33.

The Bonneterre is of especial interest because it is the formation in which the extensive ore deposits are found. Its variable characteristics are understood better if viewed in relation to the regional manifestations of these and correlative strata. The information represented graphically in Figure 6 has been compiled in order to illustrate the nature of the Bonneterre formation in the Ozark uplift region and corresponding sediments to the north and northeast.

Figure 6 consists of two cross-sections of the Bonneterre and equivalent formations. The correlations are those of the various authors[55] who have published the data and include the Eau Claire

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55 See bibliography and refer to G. V. Cohee, 1948; C. R. Fettke, 1948; F. M. Swartz, 1948; L. E. Workman and A. H. Bell, 1948; D. F. Bieberman and R. E. Esarey, 1946; J. G. Grohskopf, 1951.

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formation of Illinois, Indiana, and Ohio, and, in part, the Theresa formation of New York.

The thickness varies from 160 feet in Seneca County, Ohio, to 1600 feet in Pemiscot County, Missouri. A subsidence, at least in early Bonneterre time, is indicated in eastern Illinois and western Indiana by the increase in thickness in this area.

Coarse clastic sediments, predominant in the north, give way to finer clastic sediments southward, and these, in turn, grade into a mixture of fine clastic and calcareous sediments. The continuity of the change from coarse to fine types of lithology suggests that the subsidence in eastern Illinois and western Indiana may have been connected with the subsidence indicated by the 1600 feet of Bonneterre in the southeastern Missouri "bootheel". The coarse clastic material along the margin and the fine clastic and calcareous sediments within the area in Illinois and Indiana imply that the rate of subsidence exceeded the rate of deposition. The coarse clastic material reaches farthest south along the east and west sides of the subsidence. The abundance of coarse clastic material on the west side of the Findlay Arch as compared to the east side, and the coarse clastic facies northward suggest that the source of these sediments lies to the north and principally west of the Findlay Arch.

The deposition of clastic sediments in the subsidence in early Bonneterre time changed to chiefly calcareous sediments in later Bonneterre time. The distribution of arenaceous material in the calcareous sediments of late Bonneterre time in the Findlay Arch and Ozark uplift regions is a continuation of the trend for the distribution of coarse clastic material established in earlier Bonneterre time. Presumably the sea was too shallow in these regions for sediments to escape wave and current action. Thickening of the calcareous sediments toward the Ozark uplift is evidence that the Ozark uplift region did not contribute materially to the sediments except very locally and there only in minor amounts.

These cross-sections show that the variation in lithologic constituents of the Bonneterre formation in the Southeastern Missouri mining district is due chiefly to changes in the type of source material from other areas, the depositional environment, and the configuration of the surface upon which deposition took place.

The thickness of the formation in the mining district is irregular, principally because of its onlapping relations with the basement rock. The tendency to thin toward the west and northwest is locally modified by the irregularities on the pre-Cambrian erosional surface. The thickening is greatest southeastward in Pemiscott County.[56]

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56 J. G. Grohskopf, "Subsurface Geology of the Mississippi Embayment of Southeast Missouri," (manuscript in preparation, Missouri Geological Survey and Water Resources, Rolla, 1951).

In the area of commercial lead deposits, the thickness of the formation varies from a maximum of 600 feet in eastern Madison County to a minimum of 350 feet in the Flat River structural block. The Bonneterre is slightly less than 300 feet thick in western Washington County, and in Phelps County to the northwest, it is 250 feet thick. Mather[57] estimates a thickness of 60 feet for the formation in Morgan

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57 W. B. Mather, The Mineral Deposits of Morgan County, Missouri, Missouri Geological Survey and Water Resources, Report of Investigations No. 2, 1946. Pp. 19-20.

County, Missouri, which is approximately 100 miles northwest of the mining district. In Adair County (northeastern Missouri) 165 feet of strata are correlated with the Bonneterre.

The lower portion of the formation contains most of the commercial ore deposits and it has received more intensive study than the upper portion. It is difficult to subdivide the formation although McQueen[58] divided it, in the vicinity of Fredericktown,

58 H. S. McQueen, "Occurrence of Dolomite in the Fredericktown Area, Madison County, Missouri," Missouri Geological Survey and Water Resources, 62d Biennial Report of the State Geologist, Appendix 2, 1943.

Madison County, into four zones based on lithologic character. Stewart and Aid[59] were able to separate the formation into an upper

59 Dan R. Stewart, et al., op. cit.

and a lower member in part of the Fredericktown quadrangle, but they were unable to make a division in the northern part of the quadrangle. This inconsistency is explained as a change in the character of the formation north of the Simms Mountain fault zone (their Doe Run-Higdon fault zone). It has not been possible to establish a division of the formation which can be mapped throughout the mining district.

The Bonneterre is variable lithologically. In the Southeastern Missouri mining district, it is predominantly carbonate and is mostly a dolomite. However, considerable limestone is found at various localities. The lower portion of the formation is dolomite in the area of the commercial ore deposits, although the equivalent beds are known to be limestone elsewhere.

The chief accessory constituents of the formation are glauconite, sand and silt, shale, and detrital quartz and feldspar fragments. The beds are not consistent in composition throughout the entire mining district. Glauconite may be either absent, present in small amounts, or abundant; sand and silt range from less than one per cent to 60 per cent of the entire rock and may be present through a vertical extent ranging from less than five feet to 200 feet. The shale content varies widely also, ranging from zero to 70 per cent of the entire rock; detrital quartz and feldspar fragments may be abundant or lacking, depending upon the locality.

Glauconite occurs as irregularly shaped particles with botryoidal surfaces, as spherical pellets, and as fragments. In some areas this material constitutes 60 per cent of the rock and on weathered exposures becomes a greensand. The lateral and vertical distribution of glauconite in the lower portion of the formation is erratic. It is most abundant in a belt which includes the Flat River structural block and extends southeastward between the Simms Mountain fault zone and the Farmington anticline, and then veers eastward across the southern part of Ste. Genevieve County. To the south, in the vicinity of Fredericktown, Madison County, glauconite is present only as traces.

Sand and silt are distributed more widely and abundantly than any of the other accessory constituents. It has been noted previously that the calcareous sediments of the Bonneterre formation tend to be arenaceous in the area of the Ozark uplift. A factor influencing the distribution of the sand and silt is the configuration of the surface upon which the Bonneterre was deposited. This distribution reflects a continuation of the environment controlling the pattern of the gradational Lamotte-Bonneterre beds. This pattern is set forth in the discussion of the Lamotte formation.

Inter-bedded sand and sandy calcareous beds with arenaceous material predominant, are found in northern Iron County, southwestern St. Francois County, and northwestern Madison County. These localities are in identical relationship to the area of non-deposition of the Lamotte, and therein is a clue to the reasons for this succession of strata. Along the margins of the area of non-deposition the basal beds of the Bonneterre accumulated as near shore deposits subject to wave and current action in a gradually deepening sea. Sandy calcareous beds are predominant in this succession in off shore areas where wave and current action was less vigorous.

The vertical distribution of sand and silt in the calcareous beds of the Bonneterre apparently is dependent upon marine currents which were controlled by the topographic irregularities on the pre-Cambrian erosional surface.

Shale is a minor constituent of the Bonneterre formation throughout the mining district except in a few localities. The most striking exception is in southern Ste. Genevieve County, on the southeast flank of the Farmington anticline. Shale constitutes as much as 70 per cent of the rock in a vertical interval of five feet in the lower 100 feet of the Bonneterre, but above the transition beds. The shale frequently forms 50 per cent, commonly 30 per cent, and rarely less than 10 per cent of the rock. Elsewhere, the shale seldom exceeds 10 to 20 per cent of the rock in a sample representing a five feet vertical extent. The area of highest shale content roughly coincides with the area of highest glauconite content. In underground exposures, shale is present as thin seams along undulating bedding planes and it is unusual to find seams more than two inches thick.

The basal beds of the Bonneterre contain a mixture of silty shale and arkose in the area of non-deposition of the Lamotte formation. This material is similar to that in the Lamotte, and accordingly it is interpreted as a reworked feldspathic residuum. It is regarded as evidence for non-deposition of the Lamotte where incorporated in the Bonneterre.

The distribution of quartz and feldspar fragments in the Bonneterre is sporadic and nearly always confined to the lower portion. This distribution usually can be correlated with the position of the strata in relation to pre-Cambrian topographic highs; conglomeratic facies of the Bonneterre commonly crop out near basement rock exposures and similar material is contained in samples from some drillholes in the vicinity of known buried knobs and ridges. This association is inferred in the interpretation of underground and drillhole data where buried knobs and ridges are not yet recognized.

The method used to represent graphically the insoluble rock constituents of drillhole cuttings on a log, makes the log, in effect, a graph of the type and quantity of the principal rock components. Four lithologic components are shown quantitatively, i.e., calcareous or acid soluble material, chert, sand and silt, and shale and clay. The drillhole logs illustrated in this report show both the type and quantity of the principal rock components.

The Bonneterre formation has been established as Upper Cambrian in age by the faunal assemblage collected from it. It is conformable with the underlying Lamotte formation. The character of this contact has been discussed in connection with the Lamotte. The Bonneterre is conformable also with the overlying Davis formation of the Elvins group.

Elvins Group

The name, Elvins group, was proposed by Bain and Ulrich[60] in

60 H. Foster Bain and E. O. Ulrich, "The Copper Deposits of Missouri," United States Geological Survey, Bulletin 267, 1905. Pp. 21-26.

1905 to include:

> ...the shales, shaly limestones, and more or less earthy dolomites in St. Francois County that intervene between the shaly top of the underlying Bonneterre limestone and the cherty limestones of the Potosi group above.

The Elvins group as used in this report includes the strata lying between the Bonneterre below and the Potosi above. It includes the Davis and Derby-Doerun formations. This classification is in accordance with that used by Bridge[61] and places the base of the group

61 Josiah Bridge, "The Correlation of the Upper Cambrian Sections of Missouri and Texas with the Section in the Upper Mississippi Valley," United States Geological Survey, Professional Paper 186-L, 1936. Pp. 233-237.

some 100 feet lower stratigraphically than the base drawn by Bain and Ulrich.

The group classification is used in this discussion because the two formations differ lithologically from the underlying and overlying formations; because they are conformable; and for convenience because it is not intended to describe the formations in detail, but to discuss their regional characteristics throughout the mining district, particularly with reference to the change in type and quantity of minor lithologic constituents. The formations are differentiated on the areal geology map.

The sedimentary succession from the pre-Cambrian to the Potosi formation is conformable. The Potosi formation is said to overlap all strata down to and including in part the Bonneterre formation.[62]

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62 Dake, op. cit., p. 116

The interpretation of the overlap is the main point of this discussion.

The Elvins group as a unit usually is distinctive in its lithologic characteristics. Its non-cherty character is in sharp contrast to the overlying formations, and its argillaceous and arenaceous character is in sharp contrast to both the overlying formations and the upper portion of the underlying Bonneterre. In fact, the presence of sand and shale in the lower formation (Davis) of this group is the principal criterion for its identification. Where the sand and shale content is not distinctive, much difficulty is encountered in identifying the formation. This difficulty is believed to have been a factor leading to the postulate of overlap relations of the Potosi with all lower strata down to and including in part the Bonneterre.

Finely disseminated glauconite is a distinctive criterion for

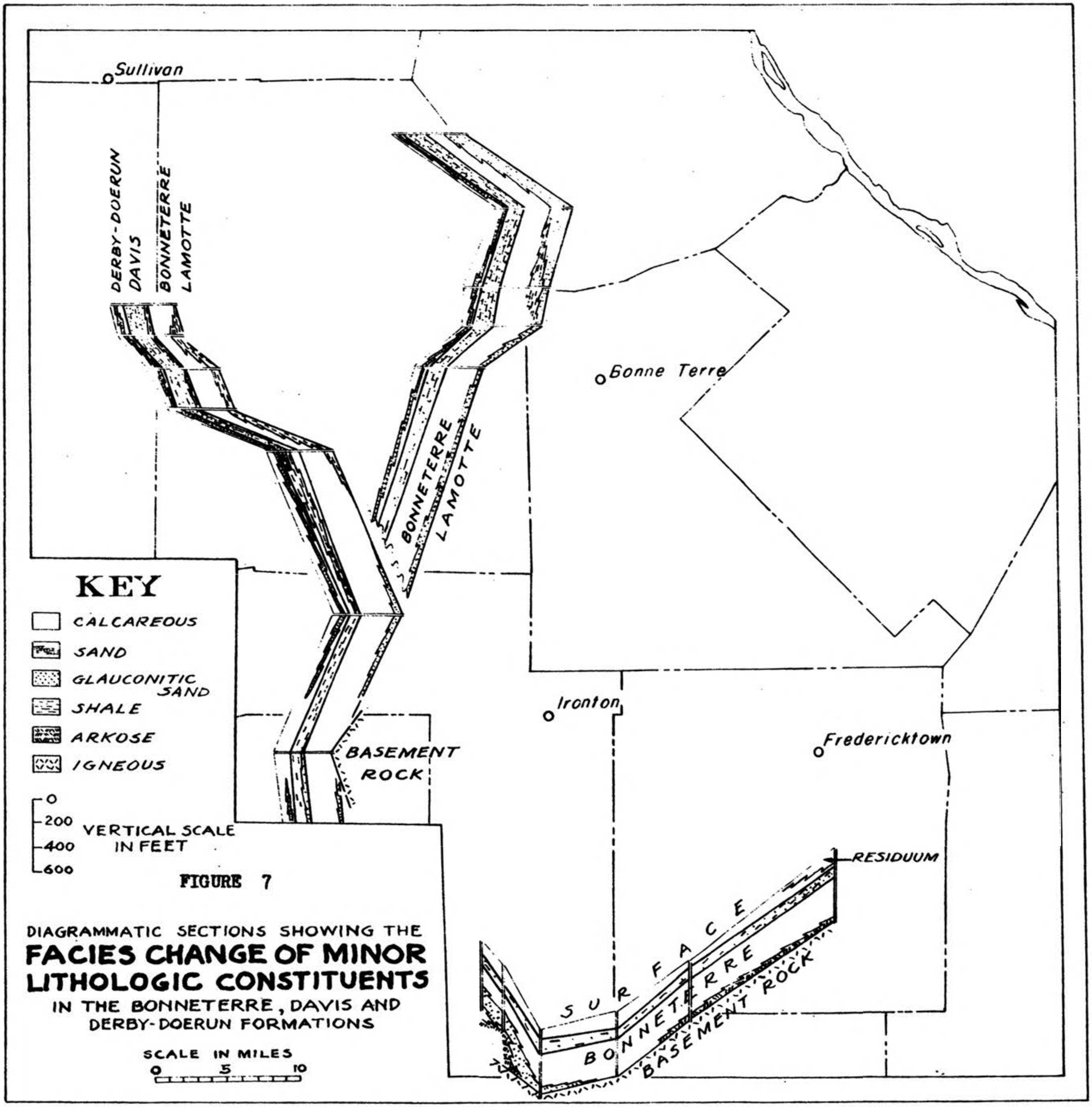

FIGURE 7

DIAGRAMMATIC SECTIONS SHOWING THE

FACIES CHANGE OF MINOR LITHOLOGIC CONSTITUENTS

IN THE BONNETERRE, DAVIS AND DERBY-DOERUN FORMATIONS the recognition of this formation in the subsurface.[63] It was noted

63 J. G. Grohskopf and Earl McCracken, Insoluble Residues of Some Paleozoic Formations in Missouri, Their preparation, Characteristics and Application, Missouri Geological Survey and Water Resources, Report of Investigations No. 10, 1949. P. 31.

in the discussion of the Bonneterre that the areas of the highest glauconite content coincided with the areas of the highest shale content. However, glauconite in appreciable quantity is distributed more widely than the shale. A similar relationship may be expected for the Davis formation. That this relationship does exist is proved by a study of samples taken throughout the mining district.

Three cross-sections in Figure 7 show the change in minor lithologic constituents and illustrate that the high sand and shale content, distinctive of the Davis formation in the northeastern portion of the district, diminishes to non-distinctive proportions in the southwestern portion. The pattern of facies change is from sand and shale, to chiefly shale, to a very small quantity of each southwestward. These changes are accompanied by a corresponding increase in calcareous material.

The thickness of the conformable strata between the Lamotte formation below and the Potosi formation above is consistent with the regional thinning of the formations. It would seem unlikely that the strata thicken so as to just compensate for the thickness of strata reported to be overlapped, thereby maintaining a constant thickness for this conformable succession.

The consistent thickness of the succession from the Lamotte to the Potosi, the change in the type of minor lithologic constituents, and the change of the quantity of these constituents with geographic position are believed to indicate that the Elvins group underlies the Potosi formation everywhere within the mining district. The slight variation in thickness of the Derby-Doerun formation suggests that an unconformity may exist at the base of the Potosi, although there are no surface exposures known to the writer which furnish evidence for unconformable relations at this contact. If this contact is unconformable the overlap relation of the Potosi involves only a part of the Derby-Doerun formation.

STRUCTURAL

The regional structural setting of the Southeastern Missouri mining district, like its stratigraphic setting, becomes more apparent when considered in connection with the regional setting of a larger structural element, the Ozark uplift, with which it is associated. The dominant structural element of the southeast Missouri region is the Ozark uplift. It is part of a broad zone of deformation extending southwestward from Pennsylvania to Oklahoma as a belt of folding and faulting.[64] This zone of deformation borders the

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64 W. H. Emmons, "The Origin of the Deposits of Sulphide Ores of the Mississippi Valley," Economic Geology, 24:221-271, 1929.

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buried extension of the Laurentian Shield.

Ancient crystalline rocks appear at the surface in the Sioux quartzite area of southwestern Minnesota, the Black Hills of western

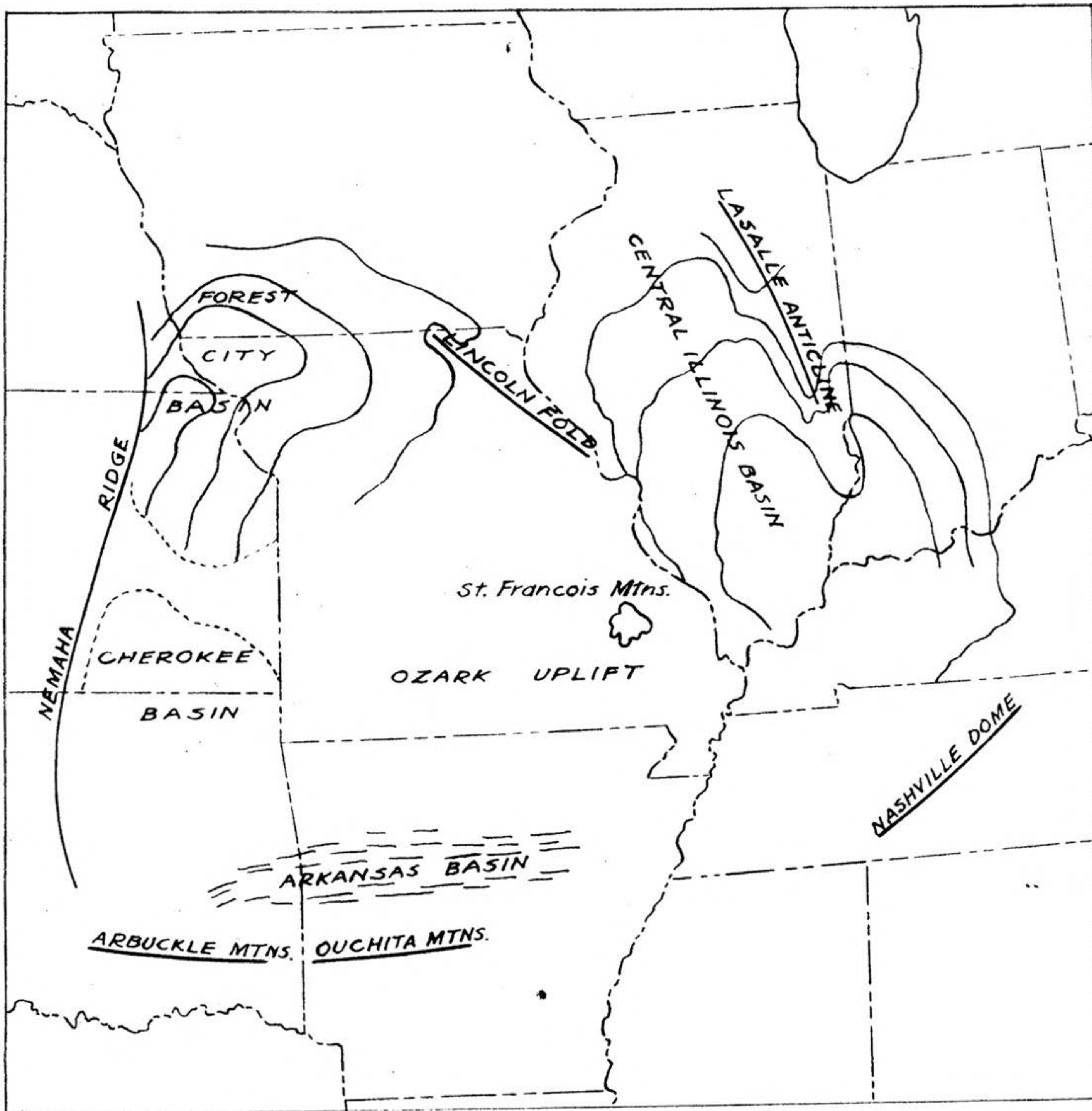

FIGURE 8

MAJOR STRUCTURAL ELEMENTS SURROUNDING THE OZARK UPLIFT

SCALE IN MILES

0 100 200

South Dakota, the Baraboo region of Wisconsin, the Arbuckle Mountains of south-central Oklahoma, the Wichita Mountains of southwestern Oklahoma, the Central Mineral Region of eastern Texas, and the St. Francois Mountains of southeastern Missouri.[65] Elsewhere, the

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65 A. W. Giles, "Structural Features of the Mississippi Valley Region and Their Relation to Mineralization," Geological Society of America, Special Paper No. 24, 1939. P. 39.

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crystalline rocks are covered by Paleozoic sediments which have been flexed into broad domes and basins. These domes and basins constitute the major structural elements of the Mississippi Valley region. Over most of the region the deformation has been slight, produced by regional warping and differential uplifts. Broad and gentle folds are superimposed locally on the major structural elements and zones of faulting have produced significant localized structural features. The Ozark uplift is one of the major structural elements in the Mississippi Valley region. Its relation to the surrounding major structural elements is shown in Figure 8.

The structural apex of the Ozark uplift is marked by the St. Francois Mountains where the ancient crystalline rocks appear at the surface over an area in excess of 200 square miles. These pre-Cambrian igneous rocks disappear in all directions beneath younger sedimentary strata. The sedimentary strata rise toward the structural apex and dip radially away from it into the Central Illinois Basin to the east, the Arkansas Basin to the south, the Cherokee Basin to the west, and the Forest City Basin to the northwest. Younger sediments are encountered at the surface in northern Missouri, northern Illinois, and Iowa. The least regional dip is toward the west into the Cherokee Basin, and the steepest is along the east flank where the sediments dip into the Central Illinois Basin. The regional dip toward the north is less than that toward the south into the Arkansas Basin. The pattern of radially dipping sediments is shown on the Geological Map of Missouri, 1939.

Isolated areas of igneous rocks which are a continuation of the central mass of pre-Cambrian rock forming the St. Francois Mountains are exposed roughly peripheral to the central mass. These exposed areas existed as topographic highs on the pre-Cambrian erosional surface at the time of initial sedimentary deposition, and the local topographic relief is known to be more than 1500 feet. As sedimentation progressed probably all of these topographic highs eventually were buried under the sediments and subsequently have been exposed by erosion.

The Ozark uplift is modified by various structural features. It is altered by linear trends of faulting and gentle folding. Locally the sediments are flexed as a result of the irregularity of the surface upon which they were deposited. Structural features associated with the uplift have a predominant northwest direction of strike. Although local features may vary from this predominant trend, they tend to align with the larger features. Faulting is most intense along the north and east flanks of the uplift and near to its structural apex.

The Southeastern Missouri mining district is located on the strongly modified north and east flanks of the Ozark uplift and near to its structural apex.

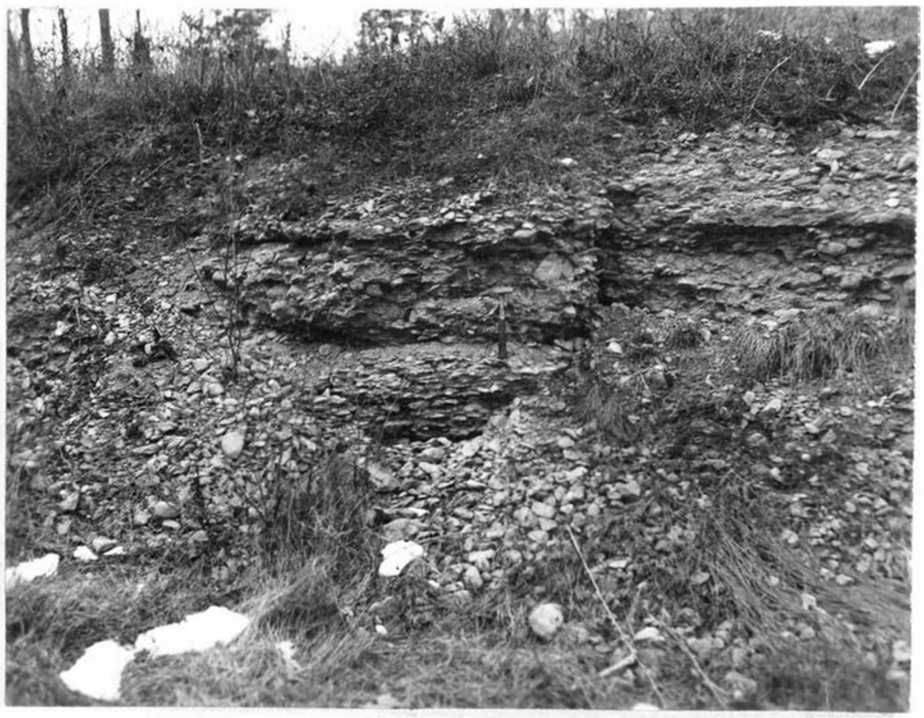

FIGURE 9

Basal cobble conglomerate along Highway N,
center sec. 20, T. 35 N., R. 4 E.

CHAPTER III

STRATIGRAPHIC AND STRUCTURAL FEATURES IN THE MINING DISTRICT

STRATIGRAPHIC

Basal Unconformity

The unconformity at the base of the sedimentary section appears to represent the longest erosional interval in the geologic column of the mining district. The rock types associated with the unconformity and their stratigraphic relations are clues to some of the early geologic history in the mining district.

Material of disintegration and decomposition from the basement igneous rock accumulated in favorable areas on the erosional surface. This residuum has been reworked into conglomerate and arkose deposits, and it has been incorporated in the sedimentary formations as intercalated beds, tongues, and wedges of arkose and silty shale.

The conglomerate is composed of fragments of igneous rock with a siliceous cement. The fragments are well rounded suggesting transportation prior to lithification. The texture is hiatal and as such indicates a degree of sorting. The larger fragments are of cobble size. The matrix consists of pebble, granule, and sand size fragments with a minor amount of siliceous material. The felsite portion of the basement rock is predominent in all sizes.

According to Pettijohn's[66] classification, this conglomerate

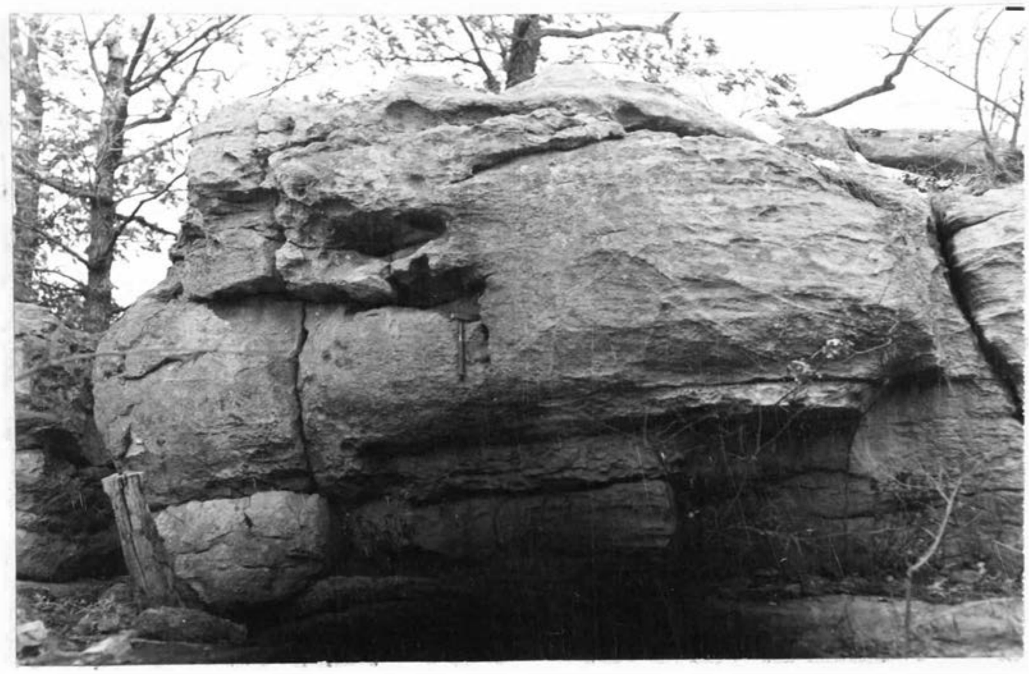

FIGURE 10

Massive poorly bedded arkose on the west side of Highway N, near center of south line sec. 20, T. 35 N., R. 4 E.

66 F. J. Pettijohn, Sedimentary Rocks (New York: Harper and Brothers, 1949), p. 196.

is an epiclastic rudite, oligomictic conglomerate, and is the deposit of a transgressive beach.

Arkose at the base of the sedimentary series is composed of crystals and fragments of quartz and feldspar, minor amounts of shale, and fragments of igneous rock rarely larger than pebble size. No attempt has been made to make a rigorous determination of the feldspar content, but it varies at different localities. The constituent particles range in size from coarse sand to granules, and rarely to pebble size. Euhedral crystals of quartz and feldspar and the angular form of other particles indicate only slight transportation. Well defined bedding and cross lamination are common although in some local areas the bedding is obscure. The arkose is rarely thick, but tends to be a thin blanket-like deposit. Arkose has been mixed with other sediments to form arkosic sandstone and conglomeratic calcareous beds. The arkose, like the conglomerate, has the nature of a deposit formed by an encroaching sea.

Red silty shale is intercalated with the Lamotte, and the basal Bonneterre beds. It represents the fine products of weathering and completes the assemblage of material derived from the pre-Cambrian mass.

The stratigraphic relation of the conglomerate and arkose is evident at a single exposure in the NW¼SW¼SW¼ sec. 34, T. 32 N., R. 6 E., along Dry Creek. The arkose overlies and grades into the

FIGURE 11

Basal cobble conglomerate and overlying conglomeratic arkose. NW$\frac{1}{4}$SW$\frac{1}{4}$SW$\frac{1}{4}$ sec. 34, T. 32 N., R. 6 E.

FIGURE 12

Silty shale and overlying calcareous beds of the Bonneterre formation. NW$\frac{1}{4}$SW$\frac{1}{4}$SW$\frac{1}{4}$ sec. 34, T. 32 N., R. 6 E.

conglomerate at the contact between the two. Near the center of sec. 20, T. 35 N., R. 4 E., the type of rock changes laterally from cobble conglomerate to pebble conglomerate with intercalated arkose beds to arkose. This transition can be traced southward along Highway N. It is a parallel relation to the vertical gradation along Dry Creek where the arkose is superjacent. The arkose was deposited around and over the conglomerate at centers of accumulation of the coarse material.

The stratigraphic relation of the conglomerate and arkose to the Lamotte formation is not clearly illustrated by a single exposure. This relation is determined best from a series of exposures in a limited area. In secs. 19 and 20, T. 35 N., R. 4 E., the Lamotte sandstone beds were traced laterally into arkose and the arkose grades into conglomerate. Lamotte sandstone in cuts along the railroad in the E$\frac{1}{2}$ sec. 19, is at the same altitude as arkose beds exposed along Highway N in sec. 20. Faulting is not indicated between these exposures.

Along Highway 32, where it crosses the north fork of Jonca Creek, in sec. 8, T. 36 N., R. 7 E., the lateral gradation of Lamotte sandstone into arkose toward the outcropping igneous rock is well shown.

The Lamotte changes vertically from arkosic sandstone in the lower beds to quartz sandstone in the higher beds, and a similar transition has been noted laterally away from basement rock exposures where the basal beds are arkosic. Because the observed transitions can be correlated with a change in position of the strata away from the basement rock, it is probable that the basal beds of the Lamotte are more or less arkosic throughout the mining district. The transition from quartz sandstone to arkose indicates contemporaneous deposition.

The stratigraphic relations of the conglomerate, arkose, and silty shale to the Bonneterre formation is illustrated at a locality in the NW$\frac{1}{4}$SW$\frac{1}{4}$SW$\frac{1}{4}$ sec. 34, T. 32 N., R. 6 E., along Dry Creek. Here the conglomerate, arkose, clay, and calcareous beds dip 10° N. 15° W. The structure is initial dip on the sloping surface of felsite basement rock which forms the hill slope to the south. The sequence upward is felsite basement rock, felsite cobble conglomerate, arkose, silty shale, and calcareous beds of the Bonneterre.

Higher on the hill an isolated outcrop of arkose occupies a position which would lie within the calcareous beds of the Bonneterre if the dip of these beds is projected. The isolated exposure is less than 100 feet from the nearest exposure of the calcareous beds of the Bonneterre. The position of the arkose indicates that the conglomerate and arkose rise along the sloping surface of the basement rock at a steeper angle than the calcareous beds, although the beds of all the types of rock appear to have the same dip. The superposition of these types of rock indicate successive deposition.

Four tongues of arkose wedge into the calcareous beds of the Bonneterre in the SW$\frac{1}{4}$SE$\frac{1}{4}$SW$\frac{1}{4}$ sec. 35, T. 34 N., R. 4 E. The wedges thin toward the north, south, and east, and the overlying beds of the Bonneterre thin onto them from the north, south, and east. Some of the calcareous beds cut out against the upper surface of the wedges.

FIGURE 13

Silty shale beds in the Lamotte.
Sec. 5, T. 33 N., R. 6 E.

FIGURE 14

Field relation of the basal cobble conglomerate and the arkose, along Highway 70, NW corner sec. 1, T. 33 N., R. 4 E.

This relationship suggests contemporaneous deposition.

The Lamotte formation contains silty shale beds at an exposure along Highway 70 at Piney Creek in Sec. 5, T. 33 N., R. 6 E. Similar silty shale is also common in the insoluble residue of drillhole cuttings from the basal beds of the Bonneterre where it rests upon the basement rock. The silty shale, like the conglomerate and arkose, is associated with both the Lamotte and Bonneterre.

Younger formations overlap onto the basement rock also and they are locally conglomeratic, but no exposures are known where the younger formations may be correlated directly with the conglomerate and arkose.

The detrital material was either incorporated into the Lamotte forming arkosic or conglomeratic sandstone or it formed distinct types of rock, but where the Lamotte is absent owing to non-deposition, this material is associated with the Bonneterre. The association of conglomerate and arkose with the Bonneterre is the principal evidence for the delineation of the area of non-deposition of the Lamotte (Fig. 2). The feldspathic residuum was incorporated in the formation first deposited at any particular locality.

STRUCTURAL

General Features

Initial Dip

The sediments commonly dip away from exposures of the basement rock. The dip in the sediments at the contact with, and immediately surrounding, topographic highs on the pre-Cambrian erosional surface is designated as initial dip by Bridge and Dake.[67]

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67 Josiah Bridge and C. L. Dake, "Initial Dip Peripheral to Resurrected Hills," Missouri Bureau of Geology and Mines, 55th Biennial Report of the State Geologist, appendix 1, 1929. Pp. 93-99.

Initial dip has been observed in stratified conglomerate, arkose, sandstone, and calcareous sediments. The greatest dips are in the calcareous sediments and may be as much as 30°. Dips as much as 20° are present in the arkose. The dip in the sandstone beds rarely exceeds 10°.

No aspect of this structural feature points to the control of the dip of the sediments more graphically than the relation of the direction of dip to the configuration of the pre-Cambrian erosional surface. Any area in the mining district in the vicinity of exposed basement rock furnishes evidence which substantiates Bridge and Dake's remarks concerning this relation. They have written:

> These dips are entirely without alignment, and in all cases peripheral to the adjacent porphyry slopes. That they are directly related to old topographic surfaces, and that they have probably not been appreciably accentuated by any subsequent local

deformation, seems to be rather conclusively demonstrated by their close conformity to the axes of the old pre-Cambrian drainage lines. ...This view is enormously strengthened, however, by the widely observed fact that the dips are towards the axial lines of the valleys; along the tributaries toward the axial lines of the tributaries; and along the sub-tributaries, toward the axial line of these, in turn.

Initial dip is not restricted to porphyry slopes, but is equally well developed adjacent to any type of basement rock. One of the better areas where the dip may be observed is along the St. Francis River and Captain Creek in T. 32 N., Rs. 5 and 6 E. It is well exhibited also along Tom Sauk and Little Tom Sauk creeks and their tributaries in Iron and Reynolds counties. The latter locality and an area in Shannon County, to the southwest of the mining district, are cited by Bridge and Dake as typical areas.

Solution Flexures

Flexures due to solution are well known throughout the Ozark uplift region of Missouri.[68] Solution structures in the area of ore

68 J Harlen Bretz, "Origin of the Filled Sink-Structures and Circle Deposits of Missouri," Bulletin of the Geological Society of America, 61:789-834, 1950.

deposits in the mining district although abundant are usually small. Considerable importance has been assigned to them in the localization of the ore minerals in the ore bodies.[69,70] Fracturing and brecci-

69 E. R. Buckley, Geology of the Disseminated Lead Deposits of St. Francois and Washington Counties, Missouri Bureau of Geology and mines, 2d ser., 9:75, 1908.

70 W. A. Tarr, "Origin of the Southeast Missouri Lead District," Economic Geology, 31:740-744, 1936.

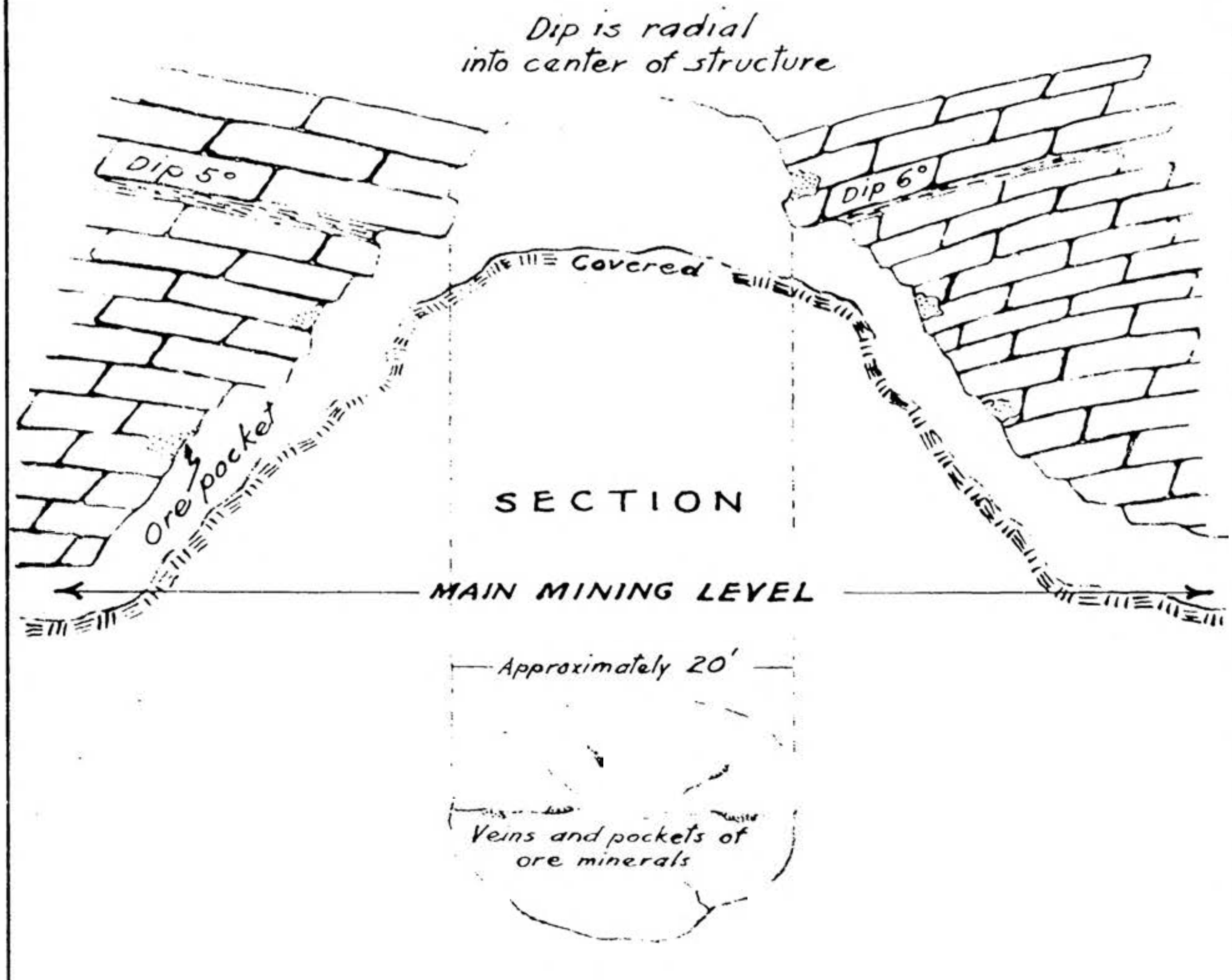

FIGURE 15

DIAGRAMMATIC SKETCH SHOWING

INFLUENCE OF SOLUTION FLEXURE UPON FORM OF THE ORE BODY

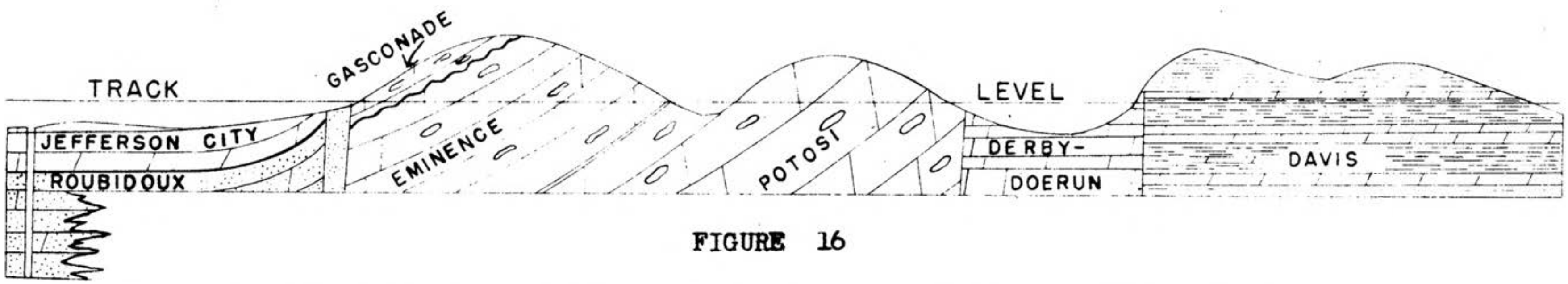

FIGURE 16

DIAGRAMMATIC CROSS-SECTION THROUGH STE. GENEVIEVE FAULT ZONE

ALONG MISSOURI PACIFIC RAILROAD
SEC. 20, T. 39 N., R. 4 E.

ation accompanying the solution structures has favored the deposition of ore minerals. On the other hand, solution structures may cut out strata favorable for mineralization and consequently an ore body may terminate at these structures. The writer has seen many excellent examples of the influence of solution structures upon the local form of the ore bodies. Figure 15 shows the relations of the mineralization to such a structure in the Garatee workings of the Valle Mines group.

Fault Drag Folding

Drag folding is a common feature along the faults. The more pronounced drag is usually on the downthrown side of the faults irrespective of the relative competency of the strata on either side. This fact is illustrated along the Ste. Genevieve fault zone where it crosses the railroad in secs. 19 and 20, T. 39 N., R. 4 E., south of Vineland, Jefferson County. The shaly Davis formation (Elvins group) on the upthrown side is nearly horizontal, but on the downthrown side, the Potosi, Eminence, and Gasconade dolomite formations, the Roubidoux sandstone and dolomite formation, and the Jefferson City dolomite formation exhibit drag folds which dip as much as 30°. A cross-section of the fault zone is shown in Figure 16.[71]

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71 Garrett A Muilenburg and Jack A. James, from the guidebook for the field conference held in connection with the 34th annual convention of the American Association of Petroleum Geologists, 1949.

Forrester[72] suggests that the fault block which was most

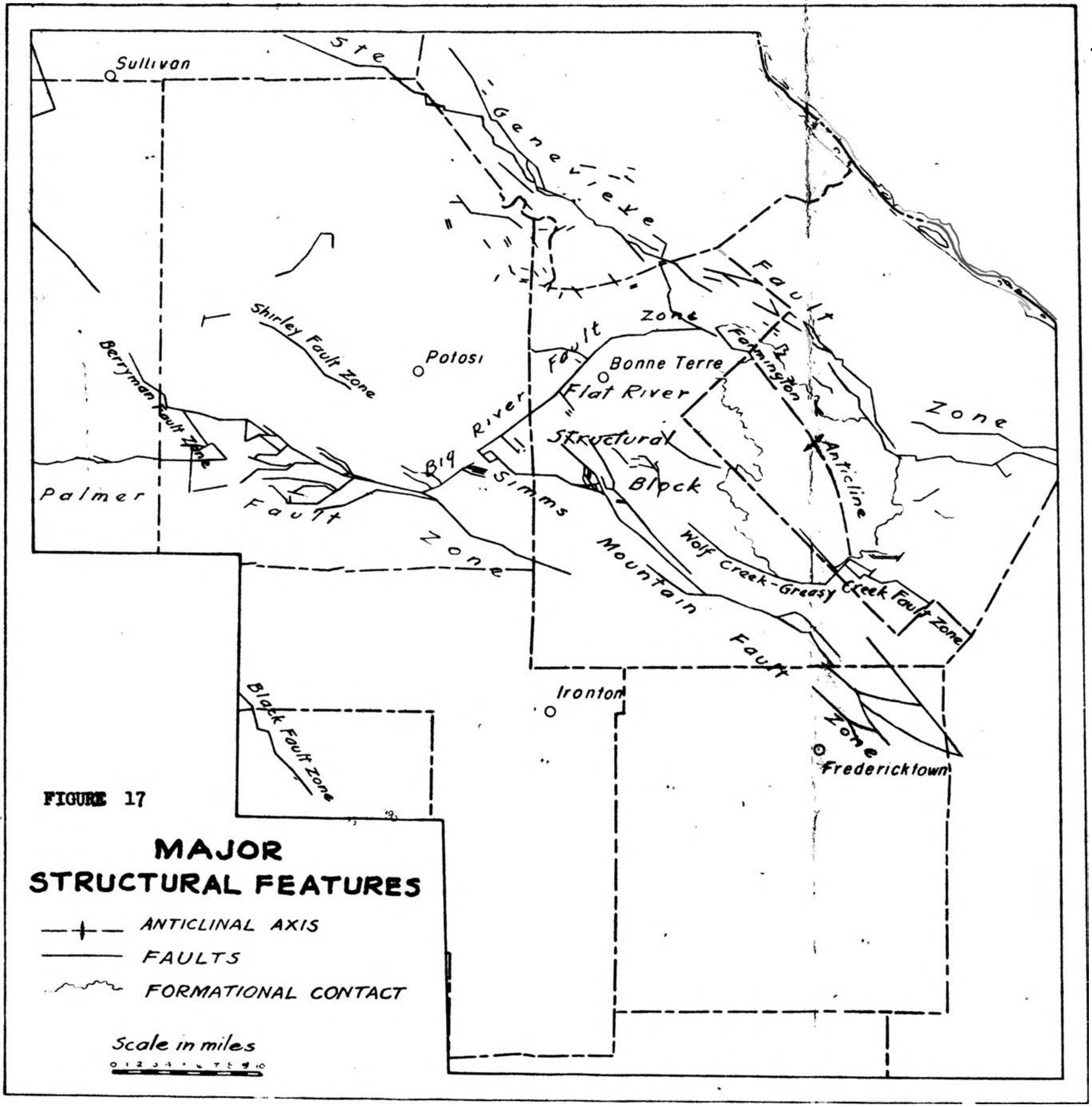

FIGURE 17

MAJOR STRUCTURAL FEATURES

72 James D. Forrester, Principles of Field and Mining Geology (New York: John Wiley and Sons, Inc., 1946), p. 48.

active is apt to exhibit more pronounced drag. This criterion, applied to the fault drag folding in the mining district, indicates that the structural apex of the Ozark uplift was relatively stable and the most active blocks were those on the flanks.

Specific Major Structural Features

The areal geology of the Southeastern Missouri mining district is a compilation of the work of many men. Structural features within the boundaries of the areas investigated by each generally were given local names for purposes of reference and identification. As a result, several names have been applied to different segments of a single major structural feature. Because it is burdensome and confusing to use several names for the same feature, the major structural features in the mining district are redefined. The name designating each of them has been chosen either because of priority of usage of the name as applied to a segment of the feature, precedence established due to layman usage, the most typical locality, or because of the locality of the most intense study. The various major structural features are indicated in Figure 17.

Farmington Anticline

The Farmington anticline, named by Weller and St. Clair,[73] is

73 S. Weller and S. St. Clair, Geology of Ste. Genevieve County, Missouri, Missouri Bureau of Geology and Mines, 2d ser., 22:37, 1928.

outlined by the nearly 110 square mile area of Lamotte outcrop in western Ste. Genevieve and eastern St. Francois counties. Pre-Cambrian igneous rock is exposed along valleys near the crest and along the east central portion of the structure.

The Farmington anticline is an open, doubly plunging fold with gently dipping limbs. The structure increases in width from three miles at the north end to 12 miles near the south end. It is approximately 20 miles long and the axis trends about N. 30° W., which roughly coincides with the watershed between the east and west drainage.

The ends of the anticline are cut by faults having a predominant northwest strike. The northward plunging nose is cut axially by a high angle fault about three miles long. The Bonneterre beds, on the downthrown side, 100 feet from the fault zone, dip 24° toward the fault. The dip increases to 53° at the fault zone. The direction of drag is the reverse of that along a normal fault, and it is not typical of reverse faulting because the drag fold is on the downthrown side. The straight line trace of the fault zone irrespective of topographic relief indicates a high angle fault plane.

The southward plunging nose is cut by a series of normal faults. Weller and St. Clair[74] mapped a zone of faulting with an

74 Weller and St. Clair, *op. cit.*

irregular course trending west-northwest across the south nose of the anticline. Stewart and Aid[75] remapped part of the area lying on the

75 Dan R. Stewart and Kenneth Aid, "Preliminary Geologic Map of the Fredericktown District," (unpublished map, Missouri Geological Survey and Water Resources, Rolla, 1943).

southward plunging nose and recognized additional faulting. The faults are short and the stratigraphic displacement probably does not exceed 50 feet. Some faults strike east, some strike northeast, and some strike northwest. The close spacing of the faults and the cross faulting pattern is responsible for the complexity of the structure in this area.

Seventy-nine igneous dikes and pipes, some of which have been called diatremes,[76,77,78,79,80,81] are distributed over the southern

76 J. E. Spurr, "The Southeast Missouri Ore-magmatic District," Engineering and Mining Journal, 122:2-12, 1926.

77 Weller and St. Clair, op. cit., pp. 248-251.

78 J. T. Singewald and Charles Milton, "An Alnoite Pipe, its Contact Phenomena, and Ore Deposition near Avon, Missouri," Journal of Geology, 38:54-66, 1930.

79 W. A. Tarr and W. D. Keller, "A Post-Devonian Igneous Intrusion in Southeastern Missouri," Journal of Geology, 41:815-823, 1933.

80 George Rust, "Preliminary Notes on Explosive Volcanism in Southeastern Missouri," Journal of Geology, 45:48-75, 1937.

81 A. L. Kidwell, Post-Devonian Igneous Activity in Southeastern Missouri, Missouri Geological Survey and Water Resources, Report of Investigations No. 4, 1947. 83pp.

nose of the Farmington anticline.

The Farmington anticline is bounded by the Ste. Genevieve fault zone for about four miles along its northeast side. The dip of the west limb continues, with only local modifications, across the Flat River structural block to the Simms Mountain and Big River fault zones.

The Farmington anticline is the east boundary of the Flat River structural block.

Ste. Genevieve Fault Zone

The Ste. Genevieve fault zone is named from Ste. Genevieve County, Missouri, where it has been most intensively studied and where it is most complex. The name is applied to that zone of faulting which extends southeast from sec. 32, T. 41 N., R. 1 E., (Franklin County) to the eastern edge of the map in T. 36 N., R. 9 E., (Ste. Genevieve County).

The Ste. Genevieve fault zone was mapped in Ste. Genevieve County by Weller and St. Clair,[82] in St. Francois and Jefferson

82 Weller and St. Clair, op. cit.

counties by Pike,[83] in Jefferson County by Parizek[84] and St. Clair,[85]

83 R. W. Pike, "Geologic Map of the Crystal City Quadrangle," (unpublished map, Missouri Geological Survey and Water Resources, Rolla).

84 Eldon J. Parizek, "Geology of the Vineland and Tiff Quadrangles in Southeastern Missouri," (unpublished Doctor's dissertation, State University of Iowa, Iowa City, 1949).

85 S. St. Clair, "Geologic Map of the De Soto Quadrangle," (unpublished map, Missouri Geological Survey and Water Resources, Rolla).

and in Franklin County by St. Clair.[86]

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86 Ibid.

This fault zone includes the faulting mapped in Ste. Genevieve County and described by Weller and St. Clair,[87] the Valle Mines

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87 Weller and St. Clair, op. cit., pp. 256-266.

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fault referred to by Buckley,[88] and the Valle Mines-Vineland fault

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88 Buckley, op. cit., p. 83.

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zone described by Parizek.[89]

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89 Parizek, op. cit., pp. 176-187.

It has a northwest trend, although the strike is nearly east from T. 36 N., R. 7 E., (Ste. Genevieve County) to the eastern edge of the map. The eastward trend continues beyond the limit of the map for nearly nine miles, almost to the Mississippi River where the northwest trend again predominates. It has been traced southeastward across the Mississippi River into Illinois. In the area covered by the accompanying map, the fault zone is 60 miles long, but the total length is more than 100 miles.

The extent and complexity of this structural feature precluded detailed field observations by the writer along its entire extent. However, the structure has been investigated previously in detail, and excellent descriptions by Weller and St. Clair[90] and Parizek[91]

90 Weller and St. Clair, *op. cit.*, pp. 256-266.

91 Parizek, *op. cit.*, pp. 176-187.

are available.

Relative movements along the fault zone have resulted in the northeast side being downthrown although opposite movement has occurred along some fault planes. The maximum total stratigraphic displacement is about 1200 feet, but the displacement along individual fault planes ranges from a few feet to several hundred feet. The maximum stratigraphic displacement is shown in Tps. 36 and 37 N., R. 7 E., where the fault zone is represented on the map as six parallel faults. The Lamotte formation on the southwest side is in juxtaposition with the Gasconade formation on the northeast side. Displacement of similar magnitude is present in the vicinity of Vineland, Jefferson County, where the faulting is more intense than any other place along the northwestern portion of the fault zone. Several sub-parallel fault planes bound a series of downfaulted blocks, and a section normal to the trend shows a series of step faults. The Davis formation at the same altitude as the Jefferson City formation indicates a stratigraphic displacement of about 1100 feet.

The surface formations involved in the faulting range in age from Upper Cambrian to Mississippian. In Illinois, beds of Pennsylvanian age are involved in the faulting.

Weller and St. Clair identified two distinct periods of faulting within the Ste. Genevieve fault zone. The basal Mississippian strata rest upon the Maquoketa-Thebes formation of Ordovician age at an altitude of 640 feet in sec. 4, T. 36 N., R. 9 E., on the north side of Little Saline Creek. On the south side of Little Saline Creek and across several intervening faults, the Mississippian strata rest upon the St. Laurent formation of Devonian age at an altitude of about 640 feet. Faulting in the bank of Little Saline Creek brings the Kimmswick formation (Ordovician) on the upthrown side (northeast) against the Bailey formation (Devonian). This faulting involves the Devonian strata, but the Mississippian strata do not appear to have been displaced.

These facts enabled Weller and St. Clair to date one movement as post-Middle Devonian. Because Pennsylvanian strata are involved in the faulting in Illinois, they dated another movement as post-Pennsylvanian. They have written:

> Unlike the late Devonian deformation which was occasioned by a stretching or lengthening of the earth's crust to produce normal faulting, this post-Pennsylvanian faulting accompanied a shortening or compression of the crust, producing faults of the reverse or thrust type.[92]

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92 Weller and St. Clair, *op. cit.*, p. 264.

Westward from the eastern edge of the map to T. 36 N., R. 7 E., a distance of about 12 miles, the fault zone is complex and consists of many parallel, sub-parallel, and branching faults. It varies in width from half a mile to three miles. The faults of the two periods of movement are separated throughout this distance and are situated in sub-parallel belts. The late Devonian faulting constitutes the northern portion of the fault zone and the post-Pennsylvanian faulting

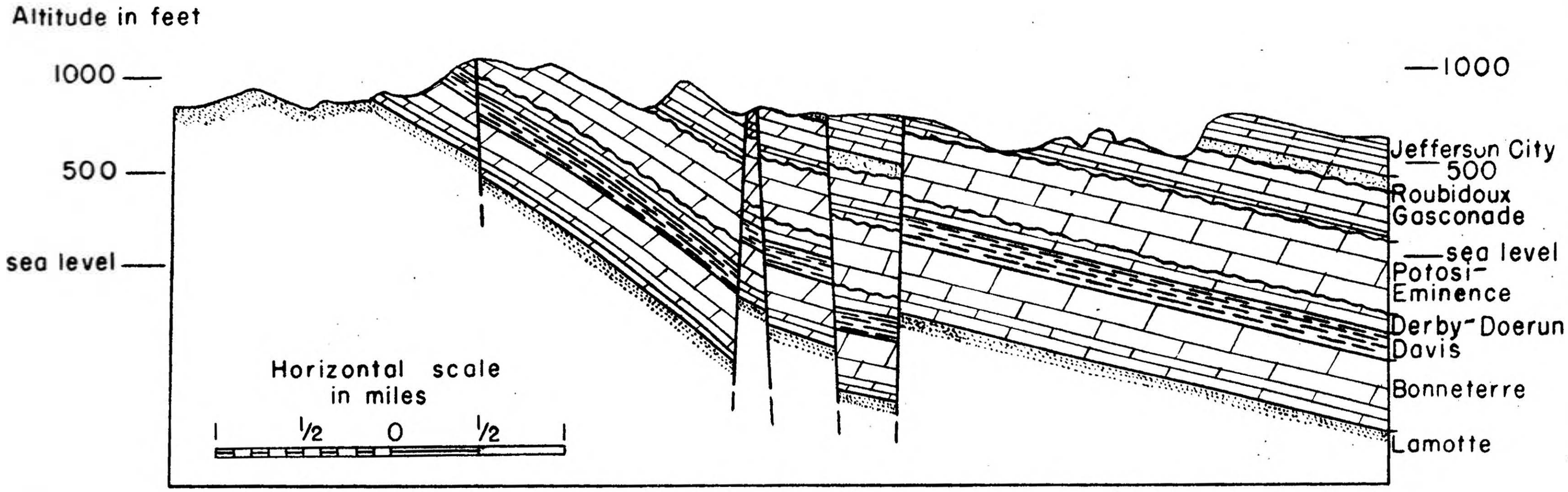

FIGURE 18

Diagrammatic cross-section of Ste. Genevieve fault zone

T.37N., R.7E.

Looking north

constitutes the southern portion. Movement along the individual faults has resulted in numerous small grabens.

The fault zone has a northwest trend from the eastern edge of T. 36 N., R. 7 E., to where it apparently dies out in Franklin County. Northwestward to the St. Francois County line, it is composed of faults belonging to the two periods of movement; the two fault systems coincide in position and it is difficult to differentiate one from the other. Also the character of the structure is different from that elsewhere along the fault zone. A cross-section (Fig. 18) illustrates this character. The fault zone consists of a series of downfaulted blocks. The aggregate displacement, downthrown to the east, is nearly matched by the displacement along the east boundary fault which is downthrown to the west. If the regional dip of the sediments to the east is projected westward, a total stratigraphic displacement across the fault zone in the magnitude of 200 feet is indicated, but a displacement of as much as 500 feet is present along a single fault plane. The small displacement across the fault zone and the larger displacements within it are in contrast to the character of this zone of faulting elsewhere along its extent.

Toward the northwest, the fault zone is less complex and it is characterized by widely spaced parallel, sub-parallel, and branching discontinuous faults with high angle fault planes. The fault zone apparently is represented by a single break at some places, but at other places it is a series of branching faults. The faulting in the vicinity of Vineland, Jefferson County, is accompanied by a change in direction of the fault zone to a more northerly course northwest of

Vineland, and it divides into two branches at the point of change in direction of strike. Each branch continues toward the northwest as a separate fault zone.

The Ste. Genevieve fault zone is the only northwest trending structure in which reverse faulting is recognized. It forms the northeast boundary of the Farmington anticline for a distance of about four miles.

Simms Mountain Fault Zone

The Simms Mountain fault zone is named from Simms Mountain in southwestern St. Francois County. The northeast side of Simms Mountain is a fault contact between the felsite forming the mountain and the sediments to the north. Tarr[93] was the first to use the term

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93 Tarr, op. cit., p. 727.

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and he suggested a correlation of his Simms Mountain fault with other faulting discovered in a reconnaissance survey to the southeast. This correlation has been established by subsequent detailed geologic mapping. Thus, the Simms Mountain fault zone of this report has a greater linear extent in a southeastern direction than that to which the name Simms Mountain was first applied.

The name is applied to that zone of faulting which starts at the Big River fault zone near Irondale, Washington County, and strikes southeast, passing near Doe Run, St. Francois County, and into Bollinger County to the east of Fredericktown, Madison County.

The Simms Mountain fault zone was mapped in Washington and St.

Francois counties by Buckley,[94] and in St. Francois, Madison, and

94 Buckley, op. cit.

Bollinger counties by Stewart and Aid.[95]

95 Stewart and Aid, op. cit.

The Simms Mountain fault zone of this report includes Buckley's Irondale fault,[96] Stewart and Aid's Doe Run-Higdon fault

96 Buckley, op. cit., p. 83.

zone,[97] and Kidwell's Irondale-Doerun-Higdon fault.[98]

97 Stewart and Aid, op. cit.

98 Kidwell, op. cit., p. 12.

The strike of the Simms Mountain fault zone conforms to the predominant northwest trend of the structural features in the mining district. A segment $2\frac{1}{2}$ miles long that strikes east constitutes the most noticeable deviation from the general northwest trend.

The fault zone has a mapped extent of about 40 miles, but reconnaissance survey shows that the southeastern extremity has not yet been fully mapped, although the end may not be far beyond the mapped area.

The Simms Mountain fault zone consists of a series of parallel, sub-parallel, and branching faults, and it is represented on the map both as a single fault and as several faults. The series of fault planes may be distributed through a width of three to four miles.

The northeast side is downthrown, but opposite movement has occurred along individual faults. The maximum stratigraphic displacement of about 600 feet is shown in sec. 29, T. 35 N., R. 6 E., where the Lamotte formation is in juxtaposition with the Potosi formation. The average is between 400 and 500 feet.

The surface formations involved in the faulting range in age from pre-Cambrian to Ordovician.

The strata are intensely faulted in the vicinity of the junction of the Simms Mountain and the Big River fault zones. The mapped pattern shows a group of nearly parallel faults, but field observations show the fault pattern to be more complex. The repetition of formations indicates many small parallel blocks or slices. The small scale of the map prohibits showing all the individual faults, and the pattern on the map illustrates the predominant structural grain.

Southeast of Irondale, the faulting is less complex and is represented on the map by a single line. Further southeast in the vicinity of Doe Run, the fault zone is represented by two distinct parallel branches about one mile apart. These two branches converge and join about four miles southeast of Doe Run. The northwestern branch is concealed in most places near Doe Run by the residual soil cover. Its position has been determined from drillhole information and by a change in character of the residual soil and, therefore, its position is only approximate and subject to change as additional drillhole information becomes available. The southwestern branch is

FIGURE 19

Silica-veined Roubidoux sandstone in the Ste. Genevieve Fault Zone. Along Missouri Pacific Railroad south of Vineland, Jefferson County.

easily traced in the vicinity of Doe Run and for 10 miles southeast because the Lamotte (sandstone) is the surface formation on the southwest or upthrown side. Silica-veined and quartzitic boulders of the sandstone mark the trace of the fault. These features are useful criteria for tracing faults in the district.

Five miles north of Fredericktown, Madison County, the fault zone has an en echelon pattern. It is difficult to trace southeastward from this locality because of the extensive residuum cover, but information from drillholes and outcrops indicates the diverging pattern. The diverging pattern and the fact that some of the faults seem to die out in a comparatively short distance may indicate that the southeastern extremity is not far beyond the mapped area.

The dip of the strata adjacent to the fault zones is mostly perpendicular to the strike, but at several places along the Simms Mountain fault zone, the dip of the beds adjacent to the fault is parallel to the strike of the faults, and, in part, may be due to initial dip.

The beds of the Bonneterre formation on the upthrown side dip 7° S. 55° E., in the SW$\frac{1}{4}$NE$\frac{1}{4}$NE$\frac{1}{4}$ sec. 15, T. 36 N., R. 3 E., at the northwest edge of Irondale. The direction of dip is parallel to the strike of the fault. Drillhole information shows a buried pre-Cambrian topographic high immediately west of this locality, and the structure may be initial dip related to the buried pre-Cambrian topographic high.

In the NW$\frac{1}{4}$NW$\frac{1}{4}$SW$\frac{1}{4}$ sec. 21, T. 36 N., R. 4 E., the lower sandy dolomite beds of the Bonneterre formation on the upthrown side dip

11° N. 30° W. This direction of dip is at an acute angle of less than 10° with the strike of the fault zone. The basement rock is exposed less than half a mile to the southeast. The Lamotte formation is exposed between the basement rock and the Bonneterre beds, and at a higher altitude than the Bonneterre. Initial dip brings the Lamotte to the surface, and the inclination of the Bonneterre beds may be due to the initial dip, or possibly to drag adjacent to an unexposed fault.

The beds of the Lamotte formation on the upthrown side dip 17° N. 50° W., in the SW$\frac{1}{4}$SW$\frac{1}{4}$NE$\frac{1}{4}$ sec. 21, T. 35 N., R. 5 E. The direction of dip is parallel to the strike of the southwest branch of the fault zone. Half a mile southeast is a small exposure of basement rock, and the structure may be due to initial dip on the flank of this projection of the basement rock.

Beds of the Lamotte sandstone on the upthrown side dip 9° W. in a direction parallel to the strike of the fault zone at the center SE$\frac{1}{4}$NW$\frac{1}{4}$ sec. 26, T. 35 N., R. 5 E. There are no exposures of basement rock nearby which might suggest that this structure is initial dip; however, a buried basement rock hill is a possibility.

The beds of the Davis formation on the downthrown side are intensely distorted in the SE$\frac{1}{4}$SE$\frac{1}{4}$NW$\frac{1}{4}$ sec. 34, T. 35 N., R. 6 E. The exposure is in a small ravine and consequently limited in extent. These beds dip 59° N., away from the fault zone. The direction of dip and the strike of the fault zone form an angle of 60°. There is no evidence that the divergence from perpendicular relations is due to initial dip.

The possibility that initial dip may control the attitude of the strata adjacent to the fault zone is suggested because of the widespread distribution and common occurrence of this structural feature on the flanks of the pre-Cambrian topographic highs. Some localities do not furnish direct evidence to support this suggestion. For instance, in sec. 21, T. 36 N., R. 4 E., the 11° dip of the sandy dolomite beds of the Bonneterre is greater than the dip of the Lamotte beds which crop out between the Bonneterre beds and the basement rock. Normally, initial dip decreases in magnitude with an increase in distance from the basement rock high. The steeper dip of the Bonneterre beds farther from the basement rock exposure may be due in part to warping accompanying movement along the fault zone. It seems probable to the writer that the dip of the beds adjacent to the fault zone at other localities may also be due in part to such warping. To what extent either warping or initial dip may have influenced the orientation of the flexures is not clear. If the orientation of the flexures reflects the direction of application of stress, a component must have acted parallel to the strike of the fault zone.

The Simms Mountain fault zone is adjacent on the northeast to the structural apex of the Ozark uplift. The terrane to the southwest of the fault is characterized by scattered knobs and indefinite ridges of basement rock surrounded by sediments. To the northeast the basement rock knobs and ridges have been dropped below the effective level of surface erosion and are still buried beneath the sediments. Two exceptions are the basement rock exposed within the

Farmington anticline and an area near the southeastern extremity of the fault zone.

The Simms Mountain fault zone is the south and southwest boundary of the Flat River structural block.

Palmer Fault Zone

The Palmer fault zone was named by Dake[99] after the town of

99 C. L. Dake, The Geology of the Potosi and Edgehill Quadrangle, Missouri Bureau of Geology and Mines, 2d ser., 23:181, 1930.

Palmer, Washington County. He included the Big River and Simms Mountain fault zones in the Palmer fault zone, but it is advantageous for purposes of discussion, reference, and identification to assign them different names. The Big River and Simms Mountain fault zones are considered as separate entities in this report. The different characteristics of each of these zones of faulting suggest their separation into three distinct structural features. The name, Palmer fault zone, is retained in this report because of priority of usage and because of the complex development in the vicinity of Palmer. However, the name is restricted to that zone of faulting which strikes northwest from near the southeastern corner of Washington County to the western edge of the map in Crawford County. It includes the Cedar Creek fault mapped by Buckley[100] and part of

100 Buckley, op. cit., p. 83.

Dake's[101] Palmer fault zone.

101 Dake, loc. cit.

The predominant northwest trend of the structural features in the mining district is reflected in the strike of the Palmer fault zone. The southern segment from the offset along the Berryman fault zone to the western edge of the map, a distance of about 12 miles, deviates from the general northwest trend and strikes nearly east.

The fault zone is 45 miles long within the area covered by the accompanying maps, but a segment that strikes west has been traced for an additional seven or eight miles beyond the western border of the map.

The northeast side is the downthrown side although opposite movement is indicated along some of the individual faults. The maximum stratigraphic displacement cannot be determined precisely from existing data. The stratigraphic position within formations of outcrops cannot be determined exactly and information is not available from drillholes contiguous to the fault zone in the area of maximum displacement. The Roubidoux in a narrow downfaulted block more than four miles long, in the NE$\frac{1}{4}$ sec. 26, T. 36 N., R. 2 E., where the Big River fault zone joins the Palmer fault zone, is in juxtaposition with the Lamotte formation. The maximum displacement here is more than 1200 feet.

The surface formations involved in the faulting range in age from pre-Cambrian to Ordovician.

The Palmer fault zone consists of a series of parallel, sub-parallel, and branching faults which form a fault zone as much as four miles wide. Individual faults strike in varied directions and locally the structure is complex. The fault zone in Washington County is characterized by a number of long narrow grabens similar in pattern to parts of the Ste. Genevieve fault zone. In contrast to the Ste. Genevieve fault zone, there is no evidence of reverse faulting.

The Palmer fault zone movement, like that along the Simms Mountain fault zone, has dropped most of the basement rock knobs and ridges north of the structural apex below the effective level of surface erosion. One exception is evident in the area between the Palmer fault zone and the Simms Mountain fault zone where the stratigraphic displacement is about 400 feet or only one-third of the maximum displacement elsewhere along the Palmer fault zone. Another exception is an area in west-central Washington County where a small cluster of basement rock knobs and ridges are exposed.

Big River Fault Zone

The Big River fault zone was named by Buckley.[102] He applied

102 Buckley, op. cit.

the name to a zone of faulting which trends northeast across the Bonne Terre quadrangle from its southwestern border. Tarr[103] and

103 Tarr, op. cit., p. 727.

Wagner[104] followed Buckley's definition. The term as used in this

104 R. E. Wagner, "'Lead Belt' Geology," Mining and Metalurgy, 28:366-368, 1947.

report applies to the same zone of faulting in the Bonne Terre quadrangle and, in addition, to extensions of the fault zone in both a southwest and northeast direction to where they are cut off by other fault zones. At its southwestern extremity, the Big River fault zone joins the Palmer fault zone; at its northeastern extremity, it joins the Ste. Genevieve fault zone.

The Big River fault zone was mapped by Dake[105] in Washington

105 Dake, op. cit.

County, by Buckley[106] in Washington and St. Francois counties, and by

106 Buckley, op. cit.

St. Clair[107] in St. Francois County.

107 Weller and St. Clair, op. cit.

This zone of faulting is of particular interest because it is the only major structural feature which deviates from the predominant northwest trend of the major structural features in the mining district. The trend is obtained by projected lines which connect isolated exposures and places where a change in the characteristics of the residual material covering the intervening spaces indicate the approximate location of the fault zone. The characteristics of the fault zone are revealed by observations at isolated exposures along its trend.

The fault zone has a general northeast trend and follows a comparatively regular course from the point of intersection with the Palmer fault in southwestern Washington County into northern St. Francois County. Throughout this distance, it has an average strike of N. 50° E. The fault zone curves eastward in northern St. Francois County and strikes about N. 75° E. to where it merges into the Ste. Genevieve fault zone.

The zone of faulting is about 24 miles long. The northwest side is downthrown, although opposite movement has occurred along individual fault planes. The Derby-Doerun formation on the upthrown side is in juxtaposition with the Potosi formation on the northwest side in the NE$\frac{1}{4}$ sec. 9, T. 36 N., R. 3 E., along Wallen Creek. The same stratigraphic relations exist in the SW$\frac{1}{4}$ sec. 36, T. 37 N., R. 3 E., along Blays Creek. The Davis formation on the upthrown side is in juxtaposition with the Derby-Doerun in the E$\frac{1}{2}$ sec. 30, T. 37 N., R. 4 E., along the unnamed branch flowing southward. The Davis is the surface formation on both the upthrown and downthrown sides in the NE$\frac{1}{4}$ sec. 16, T. 37 N., R. 4 E., along Cabanne Creek, but within the fault zone, the upthrown Bonneterre is at the surface. In the SW$\frac{1}{4}$ sec. 2, T. 37 N., R. 4 E., along the branch, the succession of formations northeastward is Davis, Bonneterre, Davis, and Derby-Doerun. Along the branch northeast of Pleasant Mound school in the center of sec. 10, T. 37 N., R. 4 E., the succession of formations from the southeast (upthrown) side to the northwest is Davis, Bonneterre, Davis. The surface formations involved in the faulting include the Bonneterre, Davis, Derby-Doerun, Potosi, and Eminence. The maximum stratigraphic displacement is about 120 feet. The lack of closely spaced stratigraphic markers within the formations makes it impossible to determine accurately the stratigraphic displacement of the individual faults.

The best exposures of the Big River fault zone are in plan view and are situated in the stream beds. The residual cover on the valley walls limits vertical sections to small irregularities in the stream bed exposures and to a few bedrock exposures in the banks. Sections more than 12 inches high are rare.

At some of the exposures it is possible to recognize individual fault planes. Their attitude cannot be determined accurately owing to the limited size of the section views, but such section views as are available suggest a high angle attitude for the fault planes.

Individual fault planes are recognized by discontinuities in bedding, by fault breccia and gouge, by an abrupt change in dip of the strata, and by a change in the formation on opposite sides of a fracture. Slickensides were not observed because they probably were destroyed by subsequent solution.

At most exposures the strike of the individual fault planes differs from the strike of the fault zone. Two individual fault planes which strike east were recognized in the NE$\frac{1}{4}$ sec. 9, T. 36 N., R. 3 E., along Wallen Creek where the fault zone trends N. 45° E. Along Blays Creek in the SW$\frac{1}{4}$ sec. 36, T. 37 N., R. 3 E., no definite fault planes were recognized, but the direction of strike of the drag folds and the trend of their northwest edge indicate that the strike of the fault planes is N. 75° E., and the fault zone trends N. 50° E. Six individual fault planes are recognized in the E$\frac{1}{2}$ sec. 30, T. 37 N., R. 4 E. They are nearly parallel and strike between N. 70° E. and N. 75° E., whereas the fault zone trends N. 50° E. Eight nearly parallel fault planes strike about N. 70° E. in the NE$\frac{1}{4}$ sec. 16, T. 37 N., R. 4 E., along Cabanne Creek, but the fault zone trends N. 50° E. Three individual fault planes strike between N. 70° E. and N. 75° E. in the SW$\frac{1}{4}$ sec. 2, T. 37 N., R. 4 E., and the fault zone trends N. 50° E. No individual fault planes are recognized in the N$\frac{1}{2}$ sec. 34, T. 38 N., R. 5 E., but the predominant set of joints, which at other exposures are parallel to the fault planes, strikes N. 75° E. By analogy a similar strike for the fault planes is indicated. The fault zone trends N. 75° E., at this place.

Brecciation is well developed at several places along the fault zone and closely spaced fracturing obliterates the bedding in belts as much as 50 yards wide. The closely spaced fracturing, brecciation, and subsequent recementation make this rock a non-descript mass. The fault zone is largely of this nature in the SW$\frac{1}{4}$ sec. 36, T. 37 N., R. 3 E., along Blays Creek. A similar type of rock outcrops in the NE$\frac{1}{4}$ sec. 9, T. 36 N., R. 3 E., along Wallen Creek. Fault breccia as much as 12 inches wide is evident at many places; it is particularly well exposed in the NE$\frac{1}{4}$ sec. 16, T. 37 N., R. 4 E., along Cabanne Creek.

Fracture cleavage is developed in the rock between two fault planes about five feet apart in the NE$\frac{1}{4}$ sec. 9, T. 36 N., R. 3 E., along Wallen Creek. The fault planes strike east and the fracture cleavage strikes N. 50° E. It is developed at several places in the NE$\frac{1}{4}$ sec. 16, T. 37 N., R. 4 E., along Cabanne Creek, and in each instance, it is in the rock between two fault planes. Here the fracture cleavage strikes N. 10° E. to N. 15° E. and the fault planes strike about N. 70° E. Slickensides along the fracture planes were not observed, although a special effort was made to find them. The enlargement of fractures by solution is prevalent, and it is likely that slickensides developed upon the fracture surfaces have been obliterated.

Sheet structure is common within the zone of faulting. Closely spaced fractures which strike parallel to the fault planes and which form sheet structure are well developed in the NE$\frac{1}{4}$ sec. 9, T. 36 N., R. 3 E., along Wallen Creek; in the NE$\frac{1}{4}$ sec. 16, T. 37 N., R. 4 E., along Cabanne Creek; in the E$\frac{1}{2}$ sec. 30, T. 37 N., R. 4 E.; and in the SW$\frac{1}{4}$ sec. 2, T. 37 N., R. 4 E. It is developed best near to the fault planes as the spacing of the fractures increases away from the fault planes, and the aspect of sheet structure is lost. However, parallel fractures are present for an appreciable distance from the fault planes, including those faults that bound the fault zone.

Other sets of joints were recognized in addition to those which parallel the fault planes and those which form fracture cleavage. At the Wallen Creek exposure, the predominant sets of joints strike N. 15° E. to N. 15° W., N. 60° W. to N. 65° W., and N. 40° E. to N. 50° E., and at the Blays Creek locality they strike N. 15° E. to N. 30° E., and N. 70° W. to N. 75° W. The predominant sets of joints strike N. 20° E., and N. 70° W., in the E½ sec. 30, T. 37 N., R. 4 E.; N. 5° E., to N. 20° E., N. 10° W. to N. 20° W., and N. 65° W., in the NE¼ sec. 16, T. 37 N., R. 4 E.; N. 10° E. to N. 20° E., N. 5° W. to N. 20° W., and N. 45° W., in the SW¼ sec. 2, T. 37 N., R. 4 E.; N. 5° E. to N. 10° E., N. 25° W. to N. 35° W., and N. 45° E. to N. 50° E., in the N½ sec. 34, T. 38 N., R. 5 E.

Drag folding is present at most of the exposures of the fault zone. That this folding is drag and not the result of a faulted flexure can be demonstrated at several exposures. The locality in the E½ sec. 30, T. 37 N., R. 4 E., illustrates drag folding particularly well. The dip of the beds of the Davis formation on the southeast (upthrown) side gradually increases toward the fault zone (northwest) to a maximum of 8°. The dip of the beds within the fault zone increases gradually from 10° N. 15° W. near the southeast border to 21° N. 15° W. near the northwest border of the fault zone. On the northwest side of a fault plane the dip of the beds increases abruptly to 37° N. 15° W. About 30 feet northwest, beyond a covered strip, the beds of the Derby-Doerun formation dip 6° N. 15° W.

The regular increase in dip of the beds as the fault zone is approached is shown in nearly continuous exposure at the Blays Creek locality. On the southeast side of the fault zone, beds of the Derby-Doerun formation dip 18° N. 15° W. Southeastward (downstream) approximately 20 paces, the beds are essentially horizontal.

Drag folding causing dips as much as 56° is exhibited along the fault zone in the NE¼NE¼SE¼ sec. 3, T. 36 N., R. 3 E. This is the maximum dip observed on drag folded beds.

To summarize, the nature of this zone of faulting is demonstrated by observations along its trend. It trends about N. 50° E. from the southwestern extremity in southeastern Washington County to northern St. Francois County where it curves eastward and strikes about N. 75° E. to the Ste. Genevieve fault zone in northeastern St. Francois County. The northwest side is downthrown, although opposite movement has occurred along some of the fault planes. The maximum stratigraphic throw is about 120 feet. Except for its northeastern portion, the trend of the fault zone and the strike of the individual fault planes vary by as much as 40°, although the usual variance is 20° to 25°. Fault breccia and fault gouge are present along some of the fault planes. Intensely brecciated and recemented rock within the fault zone form belts as much as 50 yards wide. Fracture cleavage is developed at several places and it is in the rock between fault planes. Its strike differs from the strike of the fault planes by 40° to 60°. Sheet structure is common and is present along the boundary fault planes as well as within the fault zone. Jointing forms three principal sets which strike at angles of 30° to 45°, 40° to 60°, and 75° to 90° to the strike of the fault planes. Drag folding produced dips as high as 56° in the strata adjacent to and within the fault zone. The direction of dip of the drag folds is perpendicular to the strike of the fault planes.

The Big River fault zone shows the pattern of en echelon faulting by the disparity between the strike of the fault planes and the trend of the fault zone. Fracture cleavage indicates a horizontal component of movement of the northwest (downthrown) side in a northeastward direction and it suggests compressive stress. Also, the sheet structure and intensely brecciated rock masses along the fault zone are more likely to be the result of compressive rather than tensional stress. Drag folds and the stratigraphic displacement prove the presence of a vertical component of movement.

The variation in the intensity of the deformation at different localities suggests that the stresses were not relieved uniformly along the fault zone. Instead, there are some places of intense faulting, fracturing, and brecciation, and other places where the fault zone apparently is represented by widely spaced fault planes with a nominal amount of fracturing and brecciation between them.

The change in strike of the fault zone toward its northeastern extremity may be correlated with the less intense deformation along this portion. The less intense deformation is obvious from field observations; the reasons for it are more obscure. A zone of weakness (Ste. Genevieve fault zone) to the east could have been a factor because part of the stresses acting on the Big River fault zone may have been relieved along the Ste. Genevieve fault zone.

The Big River fault zone forms the north and northwest boundary of the Flat River structural block.

Wolf Creek-Greasy Creek Fault Zone

The Wolf Creek-Greasy Creek fault zone was mapped in the Fredericktown quadrangle by Stewart and Aid[108] and in Ste. Genevieve

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108 Stewart and Aid, op. cit.

County by Weller and St. Clair;[109] however, it was named by

109 Weller and St. Clair, op. cit.

Kidwell.[110]

110 Kidwell, op. cit., p. 12.

The fault zone is situated in southeastern St. Francois County and southwestern Ste. Genevieve County. Its surface expression has been traced as far as the north line of the Fredericktown quadrangle (north edge about 1½ miles south of Farmington, St. Francois County), but it has been extended to the northwest on the basis of drillhole information and change in altitude of stratigraphic markers. The Lamotte formation was encountered in a drillhole at a depth of 224 feet at the center NE¼ sec. 2, T. 35 N., R. 5 E. Approximately 1000 feet southwest, the Lamotte formation was cut in a drillhole at a depth of 305 feet. The altitude of the Lamotte in these drillholes is 743 and 575 feet respectively, a difference of 168 feet. Both drillholes are on the southwest flank of the Farmington anticline where the dip is southwestward at the rate of about 55 feet per mile, thus, the actual displacement along the fault may be 20 feet less than that indicated by the drillhole data. It seems safe to conclude that there is a stratigraphic displacement of at least 150 feet in this locality.

Northwestwardly in T. 36 N., R. 5 E., the base of the Derby-Doerun formation rises from an altitude of 1020 feet in the SW¼SE¼ sec. 34 to an altitude of 1120 in the NW¼SW¼ sec. 35. No direct evidence of faulting was observed due to the residual soil cover, but the change in altitude of the Davis-Derby-Doerun contact suggests that faulting extends at least as far northwest as sec. 34, and may possibly connect with the zone of faulting mapped in secs. 5, 6, 8, and 16, T. 36 N., R. 5 E.

The fault zone trends southeast from its northwestern extremity and then gradually turns eastward. It strikes nearly east in the northeast corner of the Fredericktown quadrangle where the fault zone becomes more complex. Its position is offset to the northeast along a system of intersecting faults in southwestern Ste. Genevieve County. The complexity of the fault zone is due to closely spaced, criss-crossing faults which have broken the area into a mosaic pattern. The faults are short and the maximum vertical displacement probably does not exceed 50 feet.

The fault zone has been mapped to the southeastern border of Ste. Genevieve County along a northwest trend, but reconnaissance indicates its presence southeast of Ste. Genevieve County in sec. 12, T. 34 N., R. 8 E. The mapped length of more than 15 miles is extended to 20 miles by reconnaissance and drillhole information.

The southwest side is downthrown and the maximum stratigraphic displacement is probably less than 200 feet. The surface formations involved in the faulting include the Lamotte, Bonneterre, Davis, Derby-Doerun, Potosi-Eminence, and Gasconade.

The straight line trend of the fault zone trace across valleys 300 feet deep indicates that the fault planes are nearly vertical.

Faulting is indicated by discordance in altitude of stratigraphic markers, drag folds, breccia, slickensides, and zones of intense fracturing. The fault zone is hidden along much of its course in St. Francois County, and only its approximate position can be shown, but isolated exposures verify the general trend.

The Wolf Creek-Greasy Creek fault zone borders the Farmington anticline on the southwest and south, and the area of greatest complexity is on the southward plunging nose of the anticline. A graben is formed by this fault zone and the Simms Mountain fault zone about three miles southwest.

Shirley Fault Zone

The Shirley fault zone in west-central Washington County was mapped in the Potosi quadrangle by Dake.[111] It has an average strike

111 Dake, op. cit.

of N. 50° W. along a distance of about eight miles. The southeastern extremity is in the W½ sec. 19, T. 37 N., R. 2 E., and the northwestern end is in the W½ sec. 31, T. 38 N., R. 1 E. It trends toward an exposed porphyry ridge, but appears to die out before reaching the ridge.

The southwest side is downthrown, and the maximum vertical displacement is about 350 feet. The surface formations involved in the faulting are the Potosi, Eminence, Gasconade, and Roubidoux. In sec. 14, T. 37 N., R. 1 E., the Roubidoux formation has been downfaulted into juxtaposition with the central portion of the Eminence and a little more than 100 feet of the Eminence formation is exposed above the base of the Roubidoux. A drillhole in sec. 5, T. 36 N., R. 1 E., penetrated 245 feet of Gasconade and 215 feet of Eminence. On the basis of the regional geology it is safe to assume that the thickness of the Gasconade at the fault zone is 245 feet, making the total vertical displacement about 350 feet.

The trace of the fault zone is a series of irregularly oriented straight lines with an average strike of N. 50° W. The fault planes are assumed to be nearly vertical because there is no tendency for the trace of the fault zone to curve or change direction when it crosses valleys 200 feet deep.

Evidence of faulting consists of the change in altitude of certain stratigraphic markers, and, in those places where the sandstone of the Roubidoux formation is involved in the faulting, slickensides, breccia, drag folding, and quartzitic and silica-veined sandstone blocks.

A downfaulted block lies between this fault and the Palmer fault zone to the southwest.

Black Fault Zone

The Black fault zone in northeastern Reynolds County was mapped in the Edgehill quadrangle by Dake.[112] It has an average strike of N. 35° W. along a mapped distance of about nine miles. Indications of faulting are obscured by the thick residuum near the center sec. 26, T. 33 N., R. 1 E., and it has not been mapped north-

112 Dake, op. cit.

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westward beyond the western border of the quadrangle. It leaves the Edgehill quadrangle in the NW$\frac{1}{4}$ sec. 36, T. 34 N., R. 1 W.

The southwest side is downthrown and the maximum total vertical displacement possibly is 300 feet. The most accurate determination of the displacement can be made from drillhole data. A drillhole in the NE$\frac{1}{4}$NW$\frac{1}{4}$ sec. 26, T. 33 N., R. 1 E., at an altitude of 830 feet, encountered the Lamotte at a depth of 415 feet. Another drillhole in the center NW$\frac{1}{4}$ sec. 26, at an altitude of 810 feet, cut the Lamotte at a depth of 605 feet. The difference in altitude of the drillholes and the depths at which the Lamotte was encountered indicate a stratigraphic displacement of 210 feet. A drillhole in the SW$\frac{1}{4}$NW$\frac{1}{4}$NE$\frac{1}{4}$ sec. 22, T. 33 N., R. 1 E., at an altitude of 790 feet, encountered the Lamotte at a depth of 270 feet. Another drillhole in the SW$\frac{1}{4}$SE$\frac{1}{4}$NW$\frac{1}{4}$ sec. 22, at an altitude of 765 feet, entered the Lamotte at a depth of 535 feet. The depths to the Lamotte and the difference in altitude of these drillholes indicate a displacement across the fault zone of 290 feet.

The trace of the fault zone is a series of irregularly directed straight lines which have an average strike of N. 35° W. There is no tendency for the trace of the fault zone to change direction when crossing a valley 300 feet deep. In the absence of direct observations, it is inferred that the fault zone is nearly vertical.

Evidence for the fault zone is not plentiful because there are no outcropping sandstones involved in the faulting. However, the change in altitude of stratigraphic markers, slickensides, breccia, and drag folds are sufficient to establish its existence.

The Black fault zone is situated to the west of several large exposures of igneous rock. The exposed knobs on either side of the fault zone suggest the irregularity of the surface of the basement rock near it. This irregularity is the only major structural feature with which the Black fault zone is associated. It stands alone as the principal structural feature produced by deformation of the sediments in the southwestern portion of the mining district.

Berryman Fault Zone

The Berryman fault zone in west-central Washington County and east-central Crawford County was mapped in the Berryman quadrangle by James.[113] The mapped portion of this fault zone lies in T. 36 N., R. 1 W., and T. 37 N., Rs. 1 and 2 W. It has an average strike of N. 55° W. on a zig-zag course about nine miles long.

The southeastern end as mapped is in the NE$\frac{1}{4}$ sec. 15, T. 36 N., R. 1 W., at the intersection of the Berryman and the southern segment of the Palmer fault zones. Southeastward from this point of intersection, the altitude of the Potosi-Eminence contact on the southwest side of the Hazel Creek Valley is 40 feet higher than on the northeast side. This difference in altitude may reflect a monoclinal fold along the strike of the fault zone, or it may be an extension of the fault, but with slight vertical displacement due to opposite movements in the complexly faulted area at the intersection of the two fault

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113 Jack A. James, "Geology of the Berryman Area, Washington County," (unpublished Master's thesis, Missouri School of Mines and Metallurgy, Rolla, 1948).

zones.

The Berryman fault zone has not been mapped beyond sec. 10, T. 37 N., R. 2 W., but it may join the fault (Leasburg fault zone) mapped in northeastern Crawford County in T. 38 N., Rs. 2 and 3 W., and T. 39 N., R. 3 W. The trend and the direction and magnitude of differential movement along the two fault zones suggest a possible continuity.

The southwest side is downthrown, and the maximum vertical displacement is about 250 feet in secs. 14 and 23, T. 37 N., R. 2 W., where the Roubidoux formation lies against the lower portion of the Eminence formation. The surface formations involved in the faulting are the Potosi, Eminence, Gasconade, and Roubidoux. The strata northeast of the Berryman fault zone and north of the northern segment of the Palmer fault zone have been upthrown by movement along the Berryman fault zone and downthrown by movement along the Palmer fault zone. The opposite movements along the two fault zones causes an appreciable variation in the stratigraphic displacement.

The fault zone is nearly vertical as indicated by its straight line trace across valleys. Along much of its mapped extent, it intersects the surface in the valley floors where the alluvium obscures its exact position. The principal evidence for faulting is the change in altitude of stratigraphic markers from one valley wall to the other. The difference in altitude could be due to dip at some places, but at other places, faulting is the only reasonable conclusion. Later information from drillholes has substantiated the earlier fault zone interpretation of field evidence.

Flat River Structural Block

The Flat River structural block is named after the city of Flat River, St. Francois County. It lies between the Farmington anticline to the east, the Simms Mountain fault zone to the south and southwest, and the Big River fault zone to the north and northwest. This is the same area to which Tarr[114] and Wagner[115] apply the term "Lead Belt".

114 Tarr, op. cit.

115 Wagner, op. cit., pp. 366-368.

The Flat River structural block contains the extensive disseminated lead deposits which largely are responsible for the fame of the Southeastern Missouri mining district. It is discussed as a structural feature because of the associated lead deposits and because it has a structural setting not encountered elsewhere in the mining district. On the other hand, the compound character of the structural block and its size may indicate that it should be treated as a structural environment. It is treated as both a structural feature and a structural environment in this report.

The structural block is bounded by zones of faulting on the north, northwest, southwest, and south, and by an anticlinal uplift on the east. The sediments northeast of the block dip northeastward away from the structural apex of the Ozark uplift. This dip is in accord with the radial dip of contemporaneous sediments on other sides of the structural apex. Because the Flat River structural block lies between these northeastward dipping sediments and the structural apex of the Ozark uplift, it is probable that the sediments in it at one time conformed to the pattern of radial dip. The deformation has reversed the inclination of the sediments, and they now dip gently south and southwest, toward the structural apex of the Ozark uplift.

The structural block was upthrown by the movement along the Big River fault zone and it was downthrown by the movement along the Simms Mountain fault zone. The 600 feet of vertical displacement along the Simms Mountain fault zone more than compensated the opposite movement of 120 feet along the Big River fault zone and the sediments were lowered in the south and west portion of the block. Upfolding to the east tilted the sediments upward in the northeastern and eastern portion. The combination of faulting and upfolding produced the reversal of dip of the sediments.

The southwestward dip is modified by the irregular floor upon which the sediments were deposited and by the numerous faults within the structural block. This faulting will be treated in greater detail in the discussion of this feature as a structural environment.

Basement Rock Knobs and Ridges

The basement rock knobs and ridges, although physiographic features, are included in this section because of their influence on a structural environment. The pre-Cambrian surface was exposed to a long period of erosion which carved a topography with at least 1500 feet of relief prior to the first sedimentary deposition of which we have a record. The sediments were deposited by an advancing sea and the older strata cut out against the valley walls and are overlapped by younger strata. The thickness of Upper Cambrian sediments is less than the relief of the pre-Cambrian surface and some knobs and ridges were islands in the Cambrian sea. Younger sediments may have completely buried this topography, but subsequent erosion has resurrected many of the knobs and ridges which now appear as isolated hills surrounded by sediments. The sediments were deposited at a higher altitude on the flanks of the hills than in the adjacent valleys, resulting in initial dip.

Other Faulting

Other faulting in the mining district is not discussed specifically as major structural features. The faulting in the extreme northwest portion of the map (Leasburg fault zone) is not treated separately because it appears to be a continuation of the Berryman fault zone, although the continuity has not yet been traced. Faulting within the Flat River structural block is considered a part of the larger feature, and is not treated separately. The many short faults in northeastern Washington County do not constitute major structural features.

CHAPTER IV

STRUCTURAL ENVIRONMENTS AND TYPES OF ASSOCIATED ORE DEPOSITS

A structural environment is formed by either a single or a combination of structural features which were favorable for ore emplacement. Three environments have been differentiated in the district on the basis of occurrence of mineralization and the geologic setting. Each of them has associated with it a distinctive type of ore deposit which focuses attention upon the importance of structural features, and resulting structural environments, to ore emplacement.

The structural environments and their associated ore bodies are: 1) the fault zone, 2) the knob and ridge, and 3) the structural block.

Fault Zone Structural Environment

The first type of structural environment is exemplified by the conditions prevailing in the northern and northwestern portion of the mining district. The strata are broken by zones of major faulting and short, discontinuous faults. The major fault zones are complex and involve a large number of individual faults at some places, as for instance, along the Palmer fault zone in southwestern Washington County. The intricate fault pattern shown on the map undoubtedly represents only the larger breaks in a complex system of fractures which criss-cross this area and extend outward in either direction along the trend of the fault zone.

Parizek[116] mapped many short, discontinuous faults which are

116 Eldon J. Parizek, "Geology of the Vineland and Tiff Quadrangles in Southeastern Missouri," (unpublished Doctor's dissertation, State University of Iowa, Iowa City, 1949).

at a distance from the major fault zones in northeastern Washington and southwestern Jefferson counties. This pattern reveals a system of faults not recognized in previous reconnaissance surveys.

The surface formations are the Potosi and Eminence over a large area northwest of the Big River fault zone. The area northwest of the Big River fault zone and in the Bonne Terre quadrangle was mapped in 1908, before the Eminence formation had been delineated, and it was included in the Potosi formation. Further north and northwest, the Potosi and Eminence formations are differentiated on the geologic map as the result of recent mapping.

The recognition of faults in the Potosi and Eminence formations is difficult because of the thickness and uniform characteristics of each of these formations. They are 600 feet thick and, although each has a distinct lithology, the change from one to the other is gradational through about 60 feet. The lithologic uniformity of these formations precludes establishing stratigraphic markers within them. Especial difficulties are present if the vertical displacement of the faulting is less than 75 feet where the Eminence is at the surface and less than 150 feet where the Potosi is at the surface. These figures are calculated in consideration of the thickness of the formations and the average topographic relief.

Where the relief is less than normal, these figures probably should be revised upward. Faulting of even greater magnitude may exist unrecognized where the Potosi and Eminence formations are not differentiated. The Potosi and Eminence formations are undifferentiated in the area immediately northwest of the Big River fault zone, and there faulting may exist which can be determined only by drilling.

Fortunately, this difficulty is not encountered with all the formations in the mining district. The thickness of other formations and stratigraphic markers within them permit a more exact determination of stratigraphic position than is possible in the Potosi-Eminence succession of strata.

The fault zone structural environment is characterized by deformation consisting of an intricate pattern of many parallel, subparallel, and branching faults accompanied by a multitude of other planes of fracturing. Some of these zones can be inferred only by drilling, but many can be mapped from surface evidence.

Fault Zone Type Lead Ore Body

The fault zone type of lead ore body furnished most of the lead production in the early stages of development of the southeastern Missouri mining district, but is not productive now. The mine workings have been abandoned and many are inaccessible. The opportunity for direct study of this type of lead ore body is limited to those few workings which are still accessible, to an examination of the dump material, to the relative position of old shafts and pits, and to the position of the mines in relation to the areal geology.

The direct observations by the writer combined with descriptions in previous reports furnish a picture of the character of this type of lead ore body.

The ore minerals of the fault zone type of lead ore body include galena, sphalerite, barite, and smithsonite. Many of these ore bodies were exploited for galena only to find another mineral present in sufficient quantity to be a profitable accessory. Galena was the mineral exploited in some mines with barite a valuable accessory; in other mines, barite was the principal ore mineral and galena was a commercial by-product. In still other mines, sphalerite was the important ore mineral and both galena and barite were recovered as accessories. Smithsonite never has been commercially important although it has been recovered at various times.

The ratio of barite to other mineralization is much higher in the fault zone type of lead ore body than in the other types. This ratio is not included as a differentiating feature because the classification is made on a structural basis. The fault zone type lead ore body is differentiated on the mode of occurrence of the mineralization, its spatial relations, the wide stratigraphic range, the linear fracture system along the trend of the mineralization, and its relation to zones of faulting.

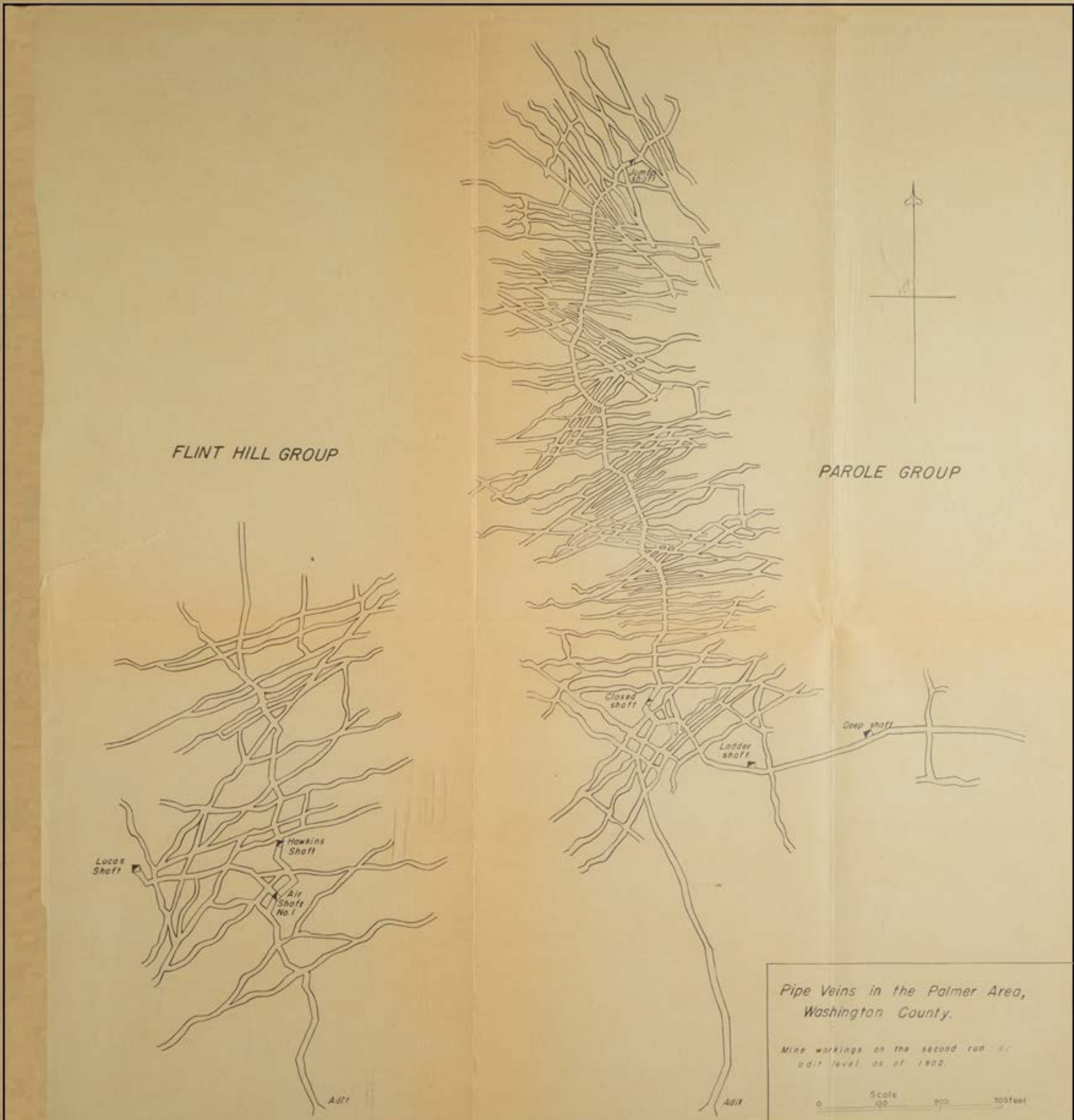
The trend of mineralization is marked by a linear system of fracture planes. In places, these fracture planes have been enlarged by solution to form channel, cave, chimney, and nearly equidimensional openings. The channels have a tabular form; the caves have a tubular form with the longitudinal axis in an essentially horizontal plane; the chimneys likewise have a tubular form, but with the longitudinal axis in an essentially vertical plane; the nearly equidimensional openings seldom extend more than two or three feet along the greatest dimension. The openings evidently were developed by differential solution along the planes of fracturing, and the resulting shape and position determines their classification.

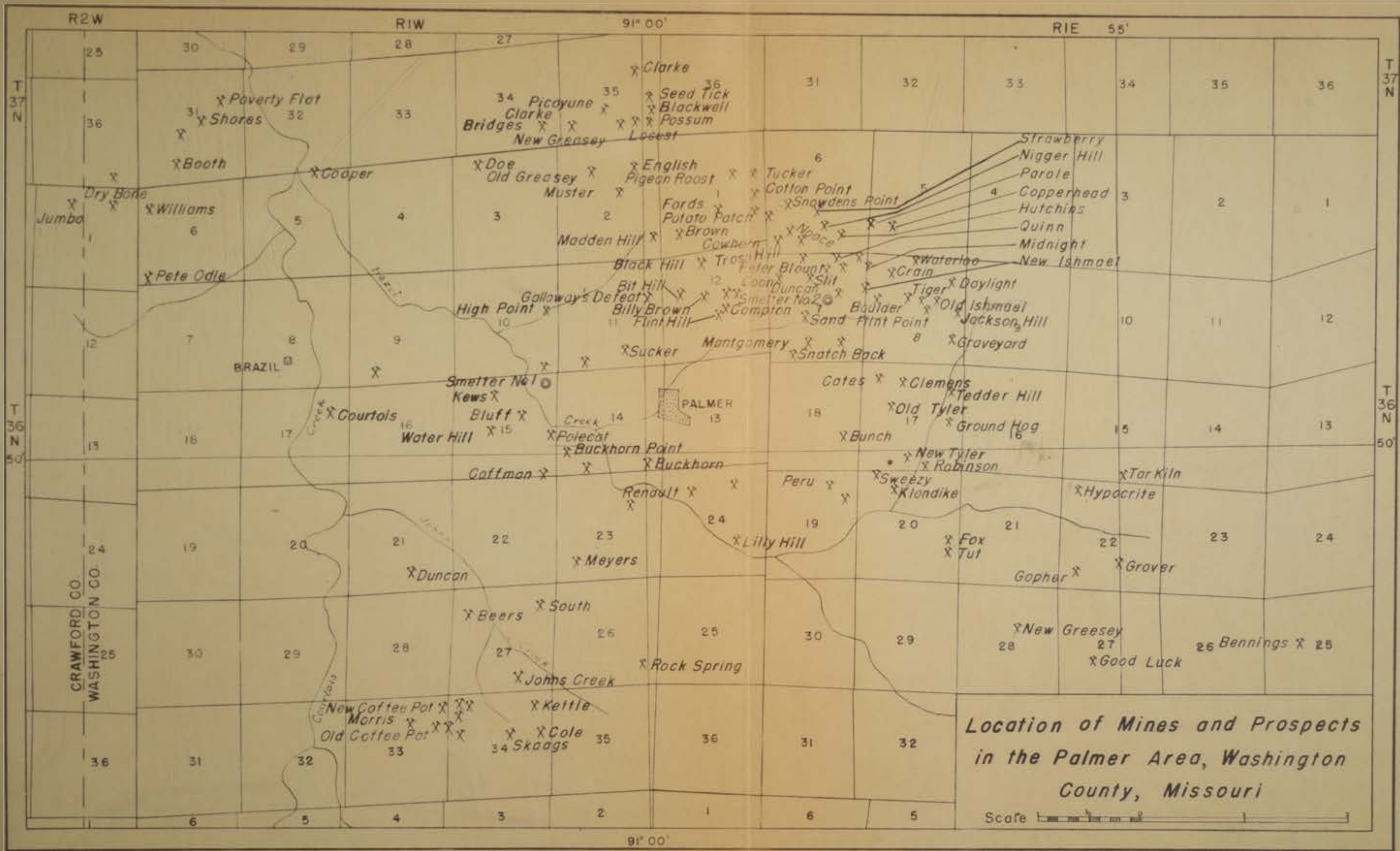
The openings commonly are filled or partially filled with a mixture of clay, loose rock fragments, gangue, and ore minerals. The ore minerals are found along the walls and intermixed in the clay and loose rock fragments, and range in size from microscopic crystals to aggregates of crystals weighing several hundred pounds. Nearly equidimensional cavities containing ore minerals are locally called ore pockets. The fractures commonly are filled with gangue and ore minerals forming narrow veins in the space between the solution openings. Broadhead[117] reported that at the Prairie Mine side runs

117 G. C. Broadhead, "The Southeast Missouri Lead District," Transactions of the American Institute of Mining Engineers, 5:100-107, 1876.

which terminated within a few feet were normal to the trend of mineralization.

The openings are discontinuous and they are either in or marginal to the zone of mineralization. Openings marginal to the zone of mineralization have been noted in all mines visited by the writer. Irregular bulges of the mine workings reflect large openings, the existence of marginally situated ore pockets, or stringers and veinlets which may or may not have terminated at ore


FLINT HILL GROUP
PAROLE GROUP
Jumbo shaft
Closed shaft
Deep shaft
Ladder shaft
Lucas Shaft
Hawkins Shaft
Air Shaft No. 1
Adit
Adit
Pipe Veins in the Palmer Area, Washington County.
Mine workings on the second run
adit level as of 1902.
Scale
0 100 200 300 feet



Location of Mines and Prospects in the Palmer Area, Washington County, Missouri

pockets.

Mine workings in the fault zone type lead ore body, in plan view, have the long, narrow outline common to vein deposits, but the restricted vertical dimension is a limitation in the third dimension as compared to vein deposits. The lateral borders of the mineralized zone are ill-defined in many places due to large openings and marginally situated ore pockets. Otherwise, the mine workings tend to maintain a fairly uniform cross-sectional size which suggests that the width of the zone of mineralization was mostly less than the minimum mining width. The spatial relations of the mineralization prompted Wheeler[118] to use the term "pipe veins" in describing the

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118 H. A. Wheeler, "Report on the Palmer Lead Property," (unpublished report made for Mr. H. J. Cantwell, 1928).

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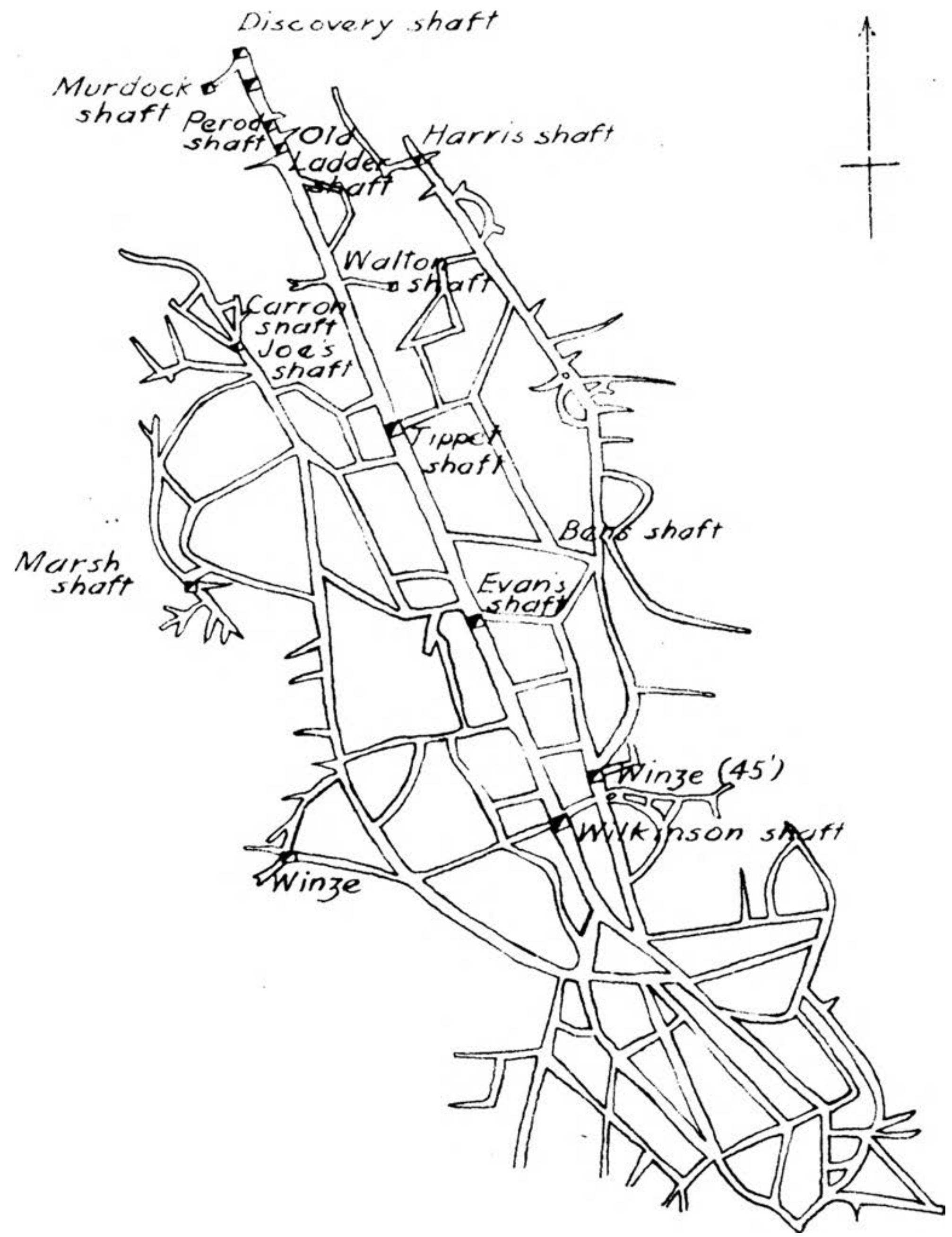
ore bodies in the Palmer area, Washington County. The plan outline of some of the pipe veins at the Parole and Flint Hill mines is shown in Figure 20. (See Figure 21 for location of these mines).

Commonly, there is more than one level of pipe veins. Three levels of mineralization were developed in the Palmer area; the second level was the most productive. The various levels of mineralization are connected by occasional chimney openings. Litton described the mode of occurrence at Valle's Mine, St. Francois County, as:

> The ore was found here in openings or caves, which, on the same level, communicated the one with the other, and which were found filled with clay, tumbling rock and mineral. Of the caves, there seem to be three series, at different depths... The second series is eighteen or twenty feet below the first, and the third



WORKINGS OF VALLE'S MINE - 1854

(From Litton's report)

SCALE IN FEET

0 100 200 300

FIGURE 22

series is about eight feet below the second.[119]

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119 A. Litton, "A Preliminary Report on Some of the Principal Mines in Franklin, Jefferson, Washington, St. Francois, and Madison Counties, Missouri," Geological Survey of Missouri, Reports I and II, Part 2, 1855. P. 35.

The plan outline of the workings at Valle's Mine shown in Figure 22 is reproduced from Litton's report.

Litton's description of Perry's mine, which is now considered a part of the Valle Mines group, points out the chimney openings connecting the various levels of mineralization. He says:

> ...the first series of caves... are found, now and then, communicating with the series below by openings or "chimneys".
>
> These caves and chimneys are filled with clay, loose rock and mineral...[120]

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120 Litton, op. cit., p. 37.

Similar chimney openings have been described from other properties in the mining district.[121] Such openings, now worked out, have been

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121 See bibliography and refer to Winslow, 1894; and Litton, 1855.

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observed by the writer in the Garatee workings of the Valle Mines group and in the Booth Mine in the Palmer area.

The pipe veins in the Palmer area are numerous small horizontal veins with galena along the walls and intermixed with clay. They range in size from two to eight feet wide and 6 to 48 inches high. Here, the lead mineralization was economically important and the ore was mined by "gophering" or "coyoting" with drifts driven on top of the bedrock or along fractures and channels within the bedrock. One limiting factor for drifting was ventilation, and the area is dotted with evidence of many air shafts. It is reported that water was an acute problem preventing deeper mining.[122]

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122 Wheeler, op. cit.

The mine workings of the fault zone type of lead ore body commonly cross stratigraphic units, rising in one place only to drop at another. The various levels may either rise and fall in unison and maintain a constant interval between them, or they may diverge or converge.

Although the stratigraphic position ranges from the Bonneterre to the Roubidoux, most of the production from this type of lead ore body is from deposits at or near the Potosi-Eminence contact. It is reported that lead was obtained from the Roubidoux sandstone at the Cove Mine, Franklin County.[123] However, the major portion of the

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123 Litton, op. cit., p. 18.

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production came from the underlying Gasconade dolomite. In that portion of the workings which is in the Roubidoux sandstone and accessible, no evidence of ore mineralization could be seen. The early mining activity in the vicinity of the disseminated deposits was concerned principally with fracture plane mineralization in the upper portion of the Bonneterre and the overlying formations.

Those mines which exploited the fault zone type of lead ore body are distributed along the major faults, but rarely in the zone of maximum displacement. Instead, the mines are marginal to the zone of maximum displacement, but within the bordering belt of intense fracturing and intricate faulting. Faults are recognizable at many of the mines, but the displacement is measured in a few inches or feet, whereas a displacement measured in tens or hundreds of feet has been mapped nearby. The position of the Valle Mines group and the mines in the Palmer area illustrates very well the relationship of mines to the zone of maximum displacement.

Exceptions to this general relationship may be the Frumet Mine along one branch of the Ste. Genevieve fault zone and the Smith and Heffner mines along the Shirley fault zone.

Many mines in the fault zone type of lead ore body lie along the trend of the Ste. Genevieve fault zone, particularly northwest of where it bounds the Flat River structural block. The McCormack Mine, where galena was mined; the Valle Mines group, important for galena, barite, sphalerite, and smithsonite; the Lee and Mammoth mines, exploited for galena and barite; the Frumet Mine, worked for galena and Sphalerite; the Darby, Ditch, Thornhill, Venable, and other mines, operated for galena and barite were located in sequence northwestward along the trend of this fault zone.

Northwest from the Flat River structural block along the Palmer fault numerous mines operated in the fault zone type of lead ore body. The Forker, Plaffy, Furnace Creek, Peach Orchard, Nigger Wool mines, the many individual operations in the Palmer area (see Fig. 21), and the Matthew, Lead Mountain, and King Mountain mines all lie along the trend of faulting. The Eye, Smith, and Heffner mines are situated along the Shirley fault zone.

The apparent lack of relation of the mines that lie between the Shirley and the Ste. Genevieve fault zones, to faulting, may be partly due to the difficulties in mapping faults in the Potosi and Eminence formations. The attitude of the mine workings and the definite trends of mineralization indicate the similarity of these ore bodies to those along known fault zones. For example, at the Lynch Mine, the ore minerals occur in cave openings having a northwest strike.[124] At the Scott and Bee mines, the mineralization was

124 A. Winslow, Lead and Zinc Deposits, Missouri Geological Survey, 7:680, 1894.

along openings striking north and east.[125] At the Prairie Mine, the

125 Winslow, *op. cit.*, p. 679.

mineralization had a north trend which was explored for several hundred feet along the strike.[126]

126 Broadhead, *op. cit.*, pp. 100-107.

The influence of the fault zone structural environment in determining the mode of occurrence of the fault zone type of lead ore body is evident from the relationship to zones of faulting, the linear fracture system along the trend of mineralization, the wide stratigraphic distribution of the mineralization, and the plan outline of the mine workings. The influence it exerted in restricting the vertical extent of the ore body and the various levels of mineralization is not clear. The fracturing and faulting provided channelways for circulation and contributed to the depositional environment as a forerunner to the formation of the fault zone type of lead ore body.

Knob and Ridge Structural Environment

The knob and ridge structural environment is illustrated in the vicinity of Fredericktown, Madison County. Fredericktown is on the southeast flank of the structural apex of the Ozark uplift, in an area of isolated knobs and indefinite ridges of basement rock which are outlying exposures of the central igneous mass. The outlying exposures are surrounded by sediments which filled valleys on the pre-Cambrian erosional surface. The greatest thickness of the sediments is in the deepest part of the buried valley. The beds thin by overlap toward the knobs and ridges where successively younger strata overlap the older beds. The southeastward regional dip is modified locally by the initial dip of the sediments surrounding the hills on the pre-Cambrian surface.

Underground observations in the Fredericktown area show both a local and a regional fracture system. Local fracturing is closely related to the contour of the hills on the basement rock surface and is roughly parallel to the horizontal trace of contact between the basement rock and the sediments. The fracture planes bend with the curvature of this contact, but they diverge where the contact turns sharply. Most of the fractures are inclined 10° to 20° from the vertical, and about half of them dip toward the hills.

The influence of the basement rock irregularities upon the fracturing has been pointed out previously,[127] but the manner in

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127 Jack A. James, Geologic Relationships of the Ore Deposits in the Fredericktown Area, Missouri, Missouri Geological Survey and Water Resources, Report of Investigations No. 8, 1949. Pp. 19-20.

---

which that influence was exerted has not been discussed in the published literature.

The trace of the basement rock-sediments contact around a knob approaches a circular form. When considered in depth to the level of the old valley floor, the knob approaches the form of a truncated cone. Actually, irregularities and deviations from a circle and cone exist, but these geometric forms are approached. The sediments are thickest in the deeper parts of the buried valley, and they become progressively thinner toward the outcrop.

The local fracture system can be explained by differential settling of the sediments surrounding the knob. The greatest settling may be either in the deepest part of the buried valley or adjacent to the knob. Differential compaction, volumetric decrease due to alteration of original rock, solution, or other unknown factors may have controlled the settling. Differential compaction and volumetric decrease due to alteration of original rock may cause the greatest settling in the deepest part of the buried valleys where the sedimentary section is thickest.

If the greatest settling is in the deepest part of the buried valley, the mechanics controlling the fracturing may be outlined as follows. Although the settling may be considered essentially a con-

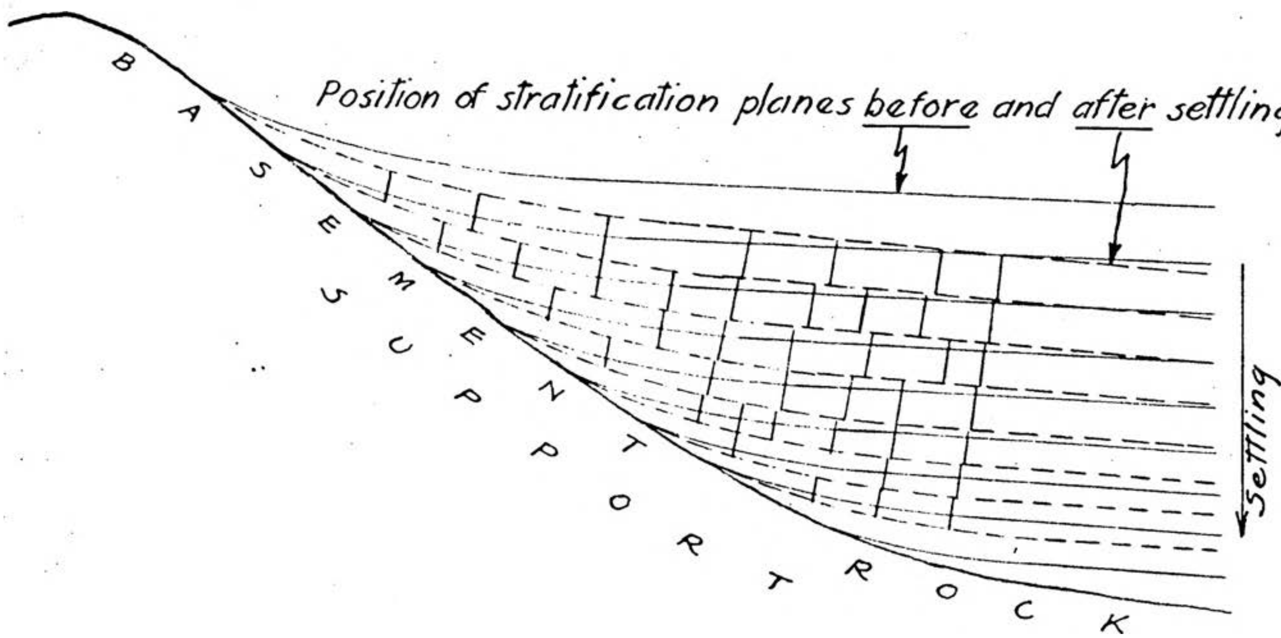


FIGURE 23

DIAGRAMMATIC SKETCH ILLUSTRATING THE
CANTILEVER ACTION OF THE SEDIMENTS
AND THE RESULTANT INCLINATION OF FRACTURES

tinuous process, the sequence necessarily must be removal of the supporting base followed by the settling of the overlying strata. Because each stratum in the area of overlap on the knob settles only slightly, resulting in a positive support at this position, each layer at positions away from the knob acts as a cantilever during the interval between the removal of support and the subsequent settling of the overlying beds. The geometric form of the supporting knob causes the cantilever action to take place radially from the knob.

Settling causes lengthening of the strata and adjustment is by fracturing as the supporting base is removed from a layer and its tensile strength is exceeded. For any two adjacent layers, the overlying one is supported by the underlying one for some distance beyond its point of fracture. Thus each successive overlying layer fractures at a point farther from the supporting knob than the layer below. Consequently, the lines of fracture in the upper layers are farther from the area of support than those in the lower layers and the fractures are inclined downward toward the area of support. The inclination of the fracture plane is believed to be the result of the same principle that accounts for the dome or arch form in connection with ground subsidence.

The fracturing would probably traverse the entire rock succession if the strata acted as a unit, but if the reaction was by massive beds acting as units, the fracturing probably would have a stair step pattern in section view. If, however, a fracture in a given bed or unit coincides with the position of a fracture in the underlying and overlying beds, the resulting fracture would traverse all the units concerned, and a stair step pattern would not be produced although the reaction was by massive units. If minute stratification planes within beds reacted as individual units, the fracture may be a reasonably smooth inclined plane. Although the discussion refers to a fracture plane, it should be understood that the stress is not relieved by a single fracture, but instead, many planes of fracturing develop in the area subjected to the stress. The cross-section pattern of the fracture planes will depend upon the magnitude of the reactive units.

Some fracture planes die out vertically. Others traverse only individual beds, while still others cross two or more adjacent beds, and some seemingly extend from the depth of the lowest mine workings to the surface. Apparently, there has been a combination of all the possible sizes of reactive units ranging from the entire succession of strata at one extreme to individual units between minute stratification planes at the other extreme.

The cantilever action of the sedimentary strata accounts for the parallel orientation of the fracture plane with respect to the outcrop line. The effective support by the knob for each stratum diminishes along a line tangent to the outcrop in each direction from the point of tangency. As the effective support is removed, the tendency to fracture decreases due to the loss of the cantilever action, and the stratum settles as a unit. Thus, the fracture planes can be expected to die out in the sediments in the buried valley. The curved trace of the fracture plane apparently reflects the adjustment in strike which tends to maintain the positive support which

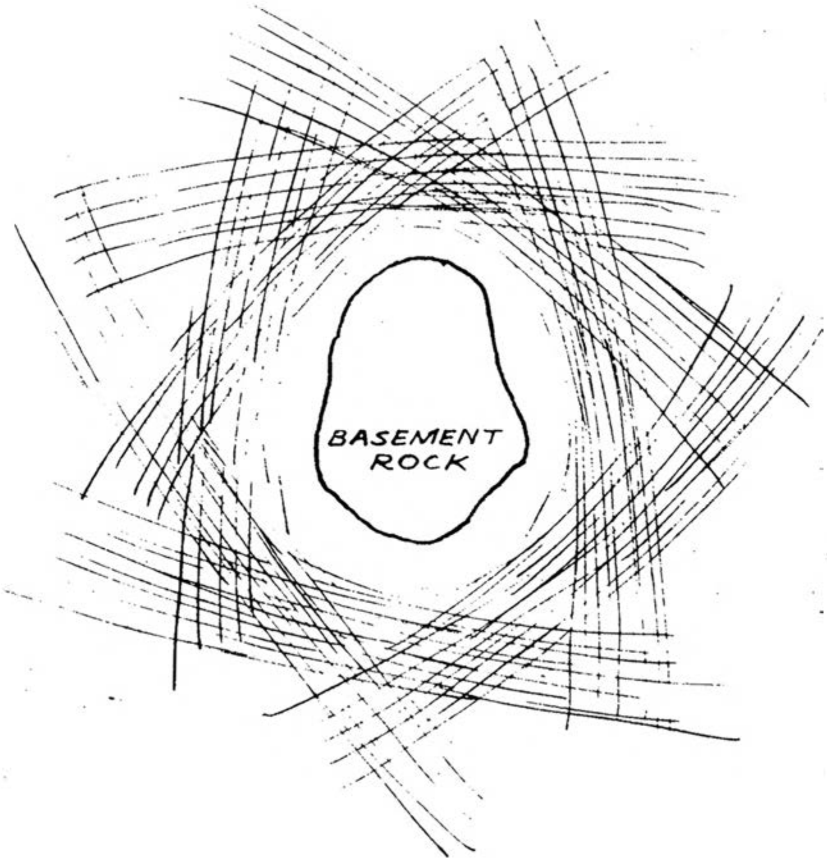


FIGURE 24

IDEALIZED DIAGRAM OF THE
FRACTURE PATTERN
ADJACENT TO A KNOB

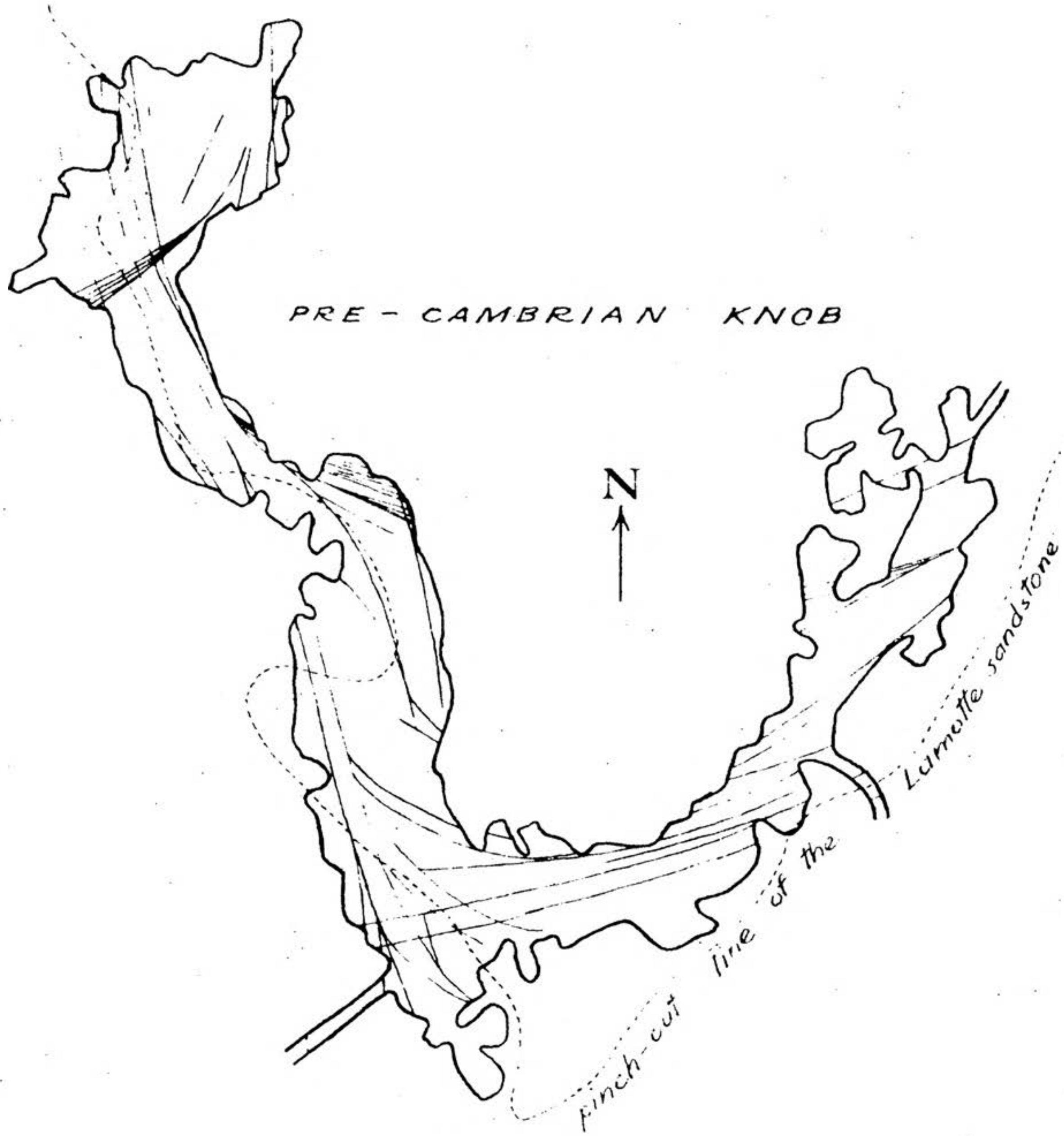


FIGURE 25

DIAGRAMMATIC SKETCH OF THE
LOCALLY CONTROLLED FRACTURE PATTERN
IN A MINE ON THE FLANK OF A PRE-CAMBRIAN KNOB
THE REGIONAL FRACTURE SYSTEM IS OMITTED
~ APPROXIMATE SCALE: 1" = 200' ~

is necessary for the lateral extension of the fracture plane.

The same principle that applies to the control of fracturing by a knob is applicable to a ridge, with certain differences due to the geometric form of a ridge. A knob supplies a support for the onlapping sediments which in plan view approaches a circular form. A ridge furnishes a support for the onlapping sediments which in plan view approaches a straight line.

Applying the principle of cantilever action around a knob to a ridge, that is, the cantilever action of the strata takes place perpendicular to the line of support, it follows that fracturing along the ridge will tend to parallel the long axis of the ridge. The parallelism may vary in detail because of the irregular outline of the ridge, but the position of the belt or zone of fracturing will not be changed materially by the small irregularities. As the longitudinal axis of the ridge changes direction of strike, so may the zone of fracturing be expected to change direction of strike.

If the greatest settling is adjacent to the knob or ridge, the mechanics of fracturing probably will be different than that discussed above. Solution could cause settling of the strata adjacent to the knob or ridge. The area effected by settling due to solution probably would flare upward as it does around a sink, and fractures dipping toward the basement rock hills would be expected. The parallel orientation of the fractures to the outcrop line follows as a corollary to solution adjacent to the knob or ridge.

The regional fracture system consists of two prominent sets of joints. One set strikes N. 15° E. to N. 40° E., and the other

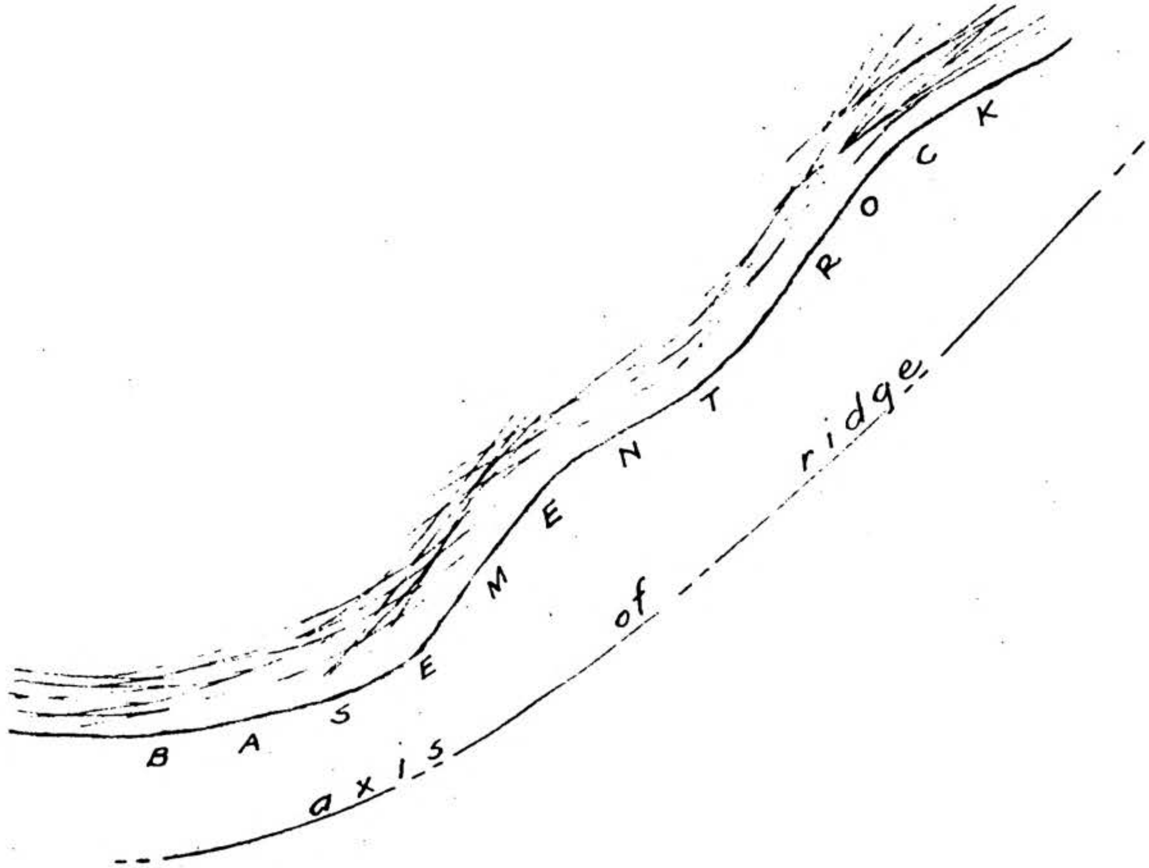


FIGURE 26

IDEALIZED DIAGRAM OF THE
FRACTURE PATTERN ALONG A RIDGE

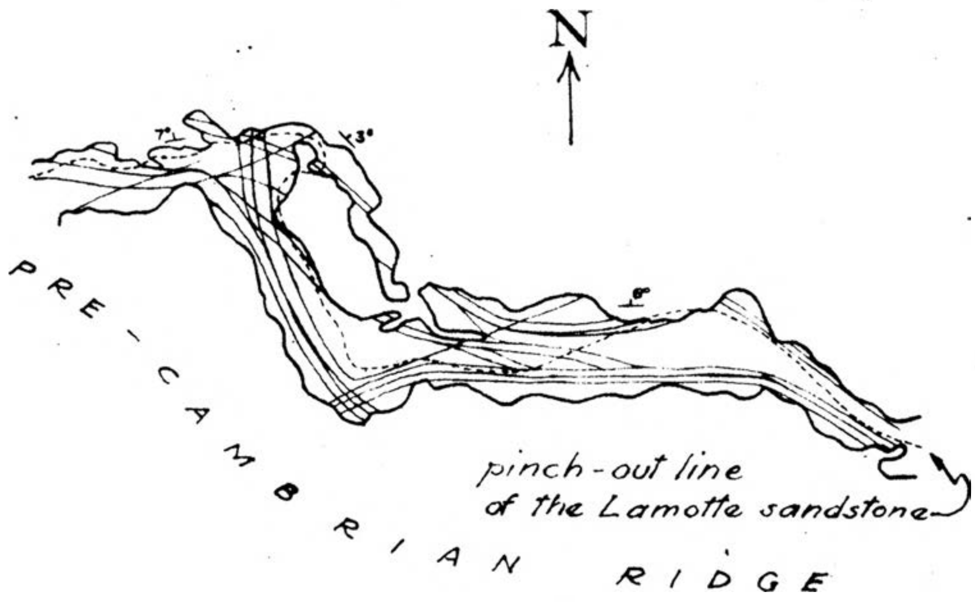


FIGURE 27

DIAGRAMMATIC SKETCH OF THE
LOCALLY CONTROLLED FRACTURE
PATTERN
IN A MINE ON THE FLANK OF A
PRE-CAMBRIAN RIDGE
THE REGIONAL FRACTURE SYSTEM IS OMITTED
~ APPROXIMATE SCALE: 1" = 400' ~

set strikes N. 45° W. to N. 70° W. The entire area has been subjected to regional deformation and fracturing has resulted throughout. Little or no correlation is apparent between the regional fracture system and the local fracture system.

This structural environment is characterized by basement rock knobs and ridges surrounded by onlapping sediments. Zones of major faulting are not part of it, although faulting with small displacement is present. This structural environment is exemplified in the vicinity of Fredericktown, Madison County, and it is present elsewhere in the mining district.

Knob and Ridge Type Lead Ore Body

The knob and ridge type of lead ore body is a minor but important source of lead production. This type is illustrated by several ore bodies in the Fredericktown area, and sixteen mines have been developed in it throughout the Southeastern Missouri mining district.

The ore minerals include galena, chalcopyrite, and siegenite; the non-metallic gangue minerals include dolomite, calcite, and quartz. Other minerals are reported in these ore bodies but only in minor amounts. The early mining at depth was for the complex copper-cobalt-nickel ores, but because of metallurgical difficulties in beneficiation, mining shifted to the extraction of lead ore, and galena is the most valuable ore mineral.

The mineralization occurs as disseminations, as horizontal sheets along bedding planes or as nearly complete replacement of beds, as veins and encrustations along fracture planes, and as a lining in cavities.

Disseminated mineralization is the most persistent and the most important source of ore, but that along bedding planes also is important. It is rarely more than two to three inches thick, although lens-like masses of marcasite-chalcopyrite-siegenite a few feet in diameter have been found. Ore minerals in small cavities are common and locally may form the entire ore body. Only a relatively small amount of sulphide mineralization occurs along the fractures, although an appreciable quantity of galena has been recovered from encrustations on the walls of those fractures which have been enlarged by solution to channels. The fracture plane mode of occurrence is most abundant in dense, fine-grained rock.

The position of the ore bodies conforms very closely to the belts of locally controlled fracturing. Locally the ore bodies are more than 200 feet wide, but the average width is near 125 feet. Their vertical extent varies considerably and the mineralization may be distributed through a height of nearly 50 feet, but it usually is less than 10 feet thick. The discontinuous character and the resulting ellipsoidal form of the individual ore bodies suggest numerous loci of deposition. The restricted width and vertical height, and the position relative to the knobs and ridges are diagnostic features of this type of lead ore body.

The stratigraphic position of the mineralization has been described in a recent publication.[128] Ore bodies are confined to the

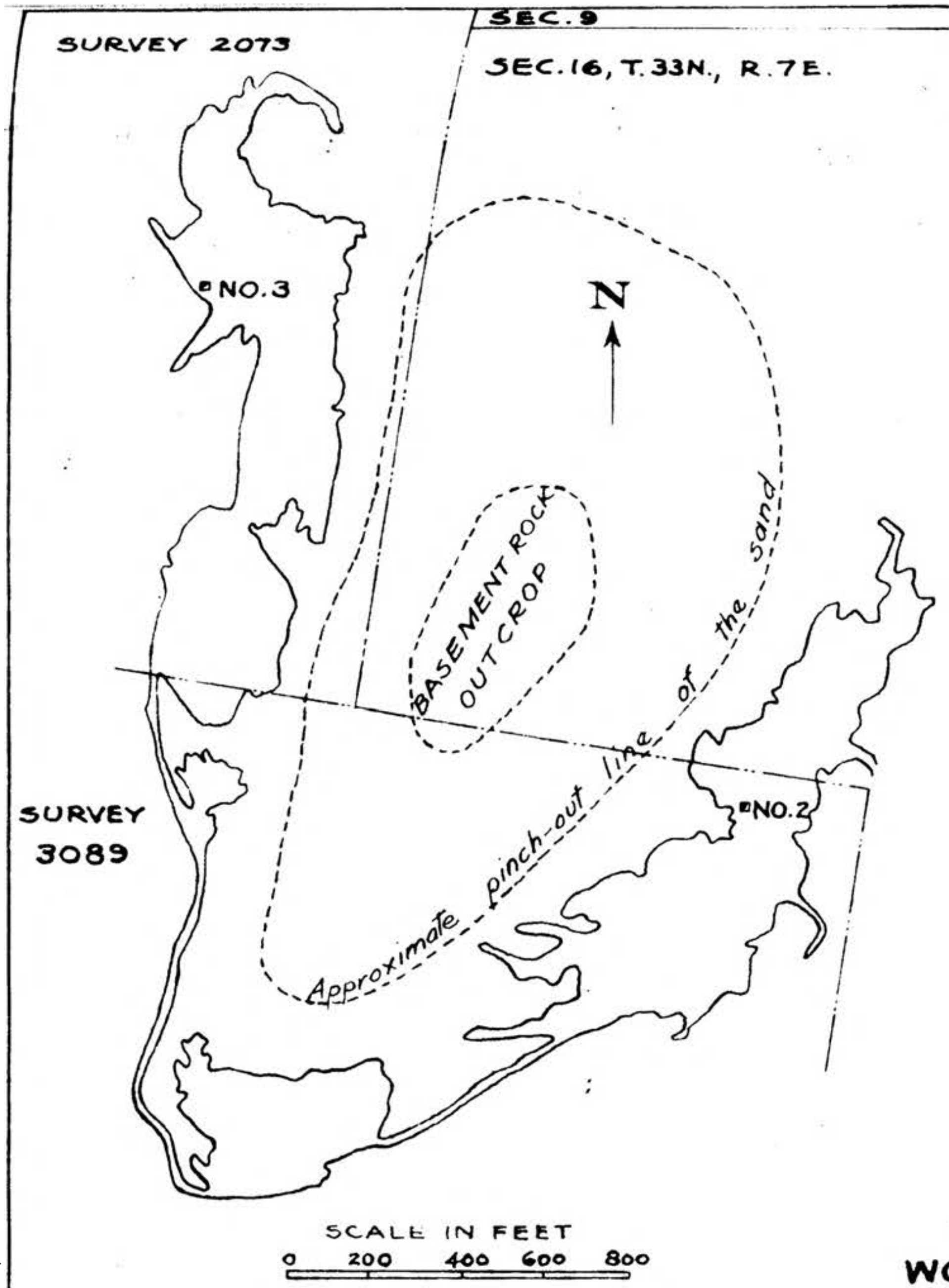
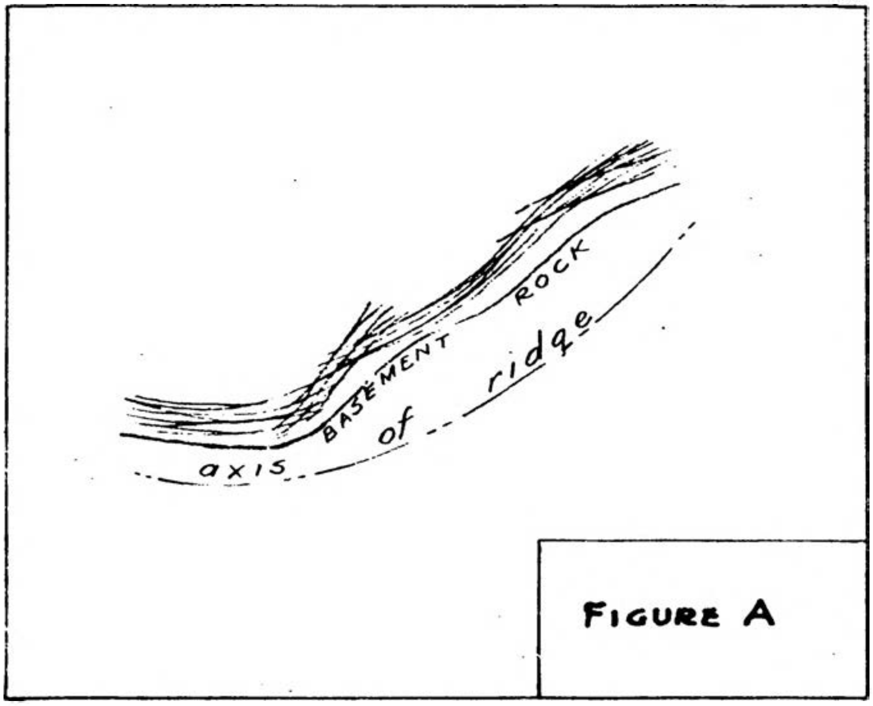
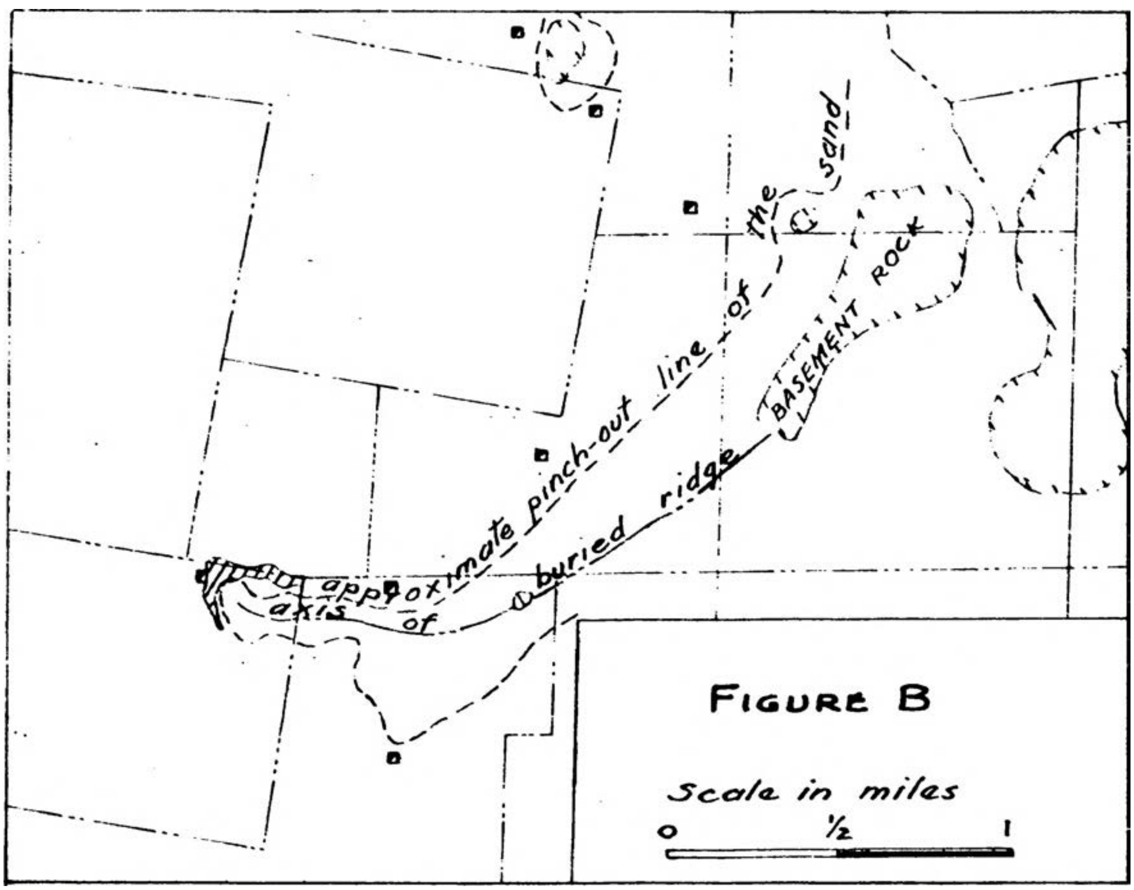


FIGURE A

FIGURE B

COMPARISON OF POSITIONS OF MINE WORKINGS AND THE IDEALIZED FRACTURE PATTERN ADJACENT TO A KNOB





COMPARISON OF POSITIONS OF MINES AND THE IDEALIZED FRACTURE PATTERN ALONG A RIDGE

128 James, op. cit., pp. 20-21.

lower 50 feet of the Bonneterre formation as exposed in the mine workings, but exceptionally, ore has been found extending into the underlying Lamotte formation. Correlation of the strata in which the ore is found has been established by the study of insoluble residues. Mineralization occurs stratigraphically higher than the lower 50 feet of the Bonneterre formation, but no commercial ore bodies have been discovered in the Fredericktown area in the higher strata.

The ore bodies are structurally high because of their position on the flanks of the knobs and ridges where the strata rise along the slope of the basement rock surface.

The coincident positions of the belt of fracturing and the ore bodies can be shown best by means of illustrations. The correlation of the position of the mine workings at the Missouri Cobalt Company mine with the idealized fracture pattern is shown in Figures A and B, Plate I. A plan outline of mine workings along a ridge to illustrate a similar parallelism is not available. However, this relationship is evident from Plate II, Figures A and B, which show the pinch-out line of the Lamotte formation, the axis of a buried ridge, and the position of five shafts. The mine workings at one of the shafts suggests their shape at the other shafts.

Faulting is recognizable in the mines, but it is of small magnitude and appears to have been important only locally to emplacement of the ore. The most effective factor in localizing the ore bodies is the fracturing.

Structural Block Environment

This environment is illustrated by the geologic setting in the Flat River structural block, and it influenced the formation of the extensive disseminated lead deposits.

The Flat River structural block was created by a series of faults on the north, northwest, southwest, and south and by an anticlinal feature on the east. The northeastward dip of the sediments northeast of the structural block is in accord with the radial dip of contemporaneous sediments on other sides of the structural apex. Because the Flat River structural block lies between these northeastward dipping sediments and the apex, the sediments in it at one time probably conformed to the pattern of radial dip. The deformation has reversed this inclination and the sediments now dip gently southwest, toward the apex of the Ozark uplift.

Movements along the Ste. Genevieve fault zone to the east and northeast, the Big River fault zone to the north and northwest, the Simms Mountain fault zone to the southwest and south, and upfolding expressed by the Farmington anticline to the east has brought about the reversal of dip. The sediments were upthrown by movement along the Ste. Genevieve and Big River fault zones and dropped by movement along the Simms Mountain fault zone. Upfolding at the position of the Farmington anticline tilted the sediments upward to the east.

The southwestward dip is modified at various localities within the structural block by the irregular floor upon which the sediments were deposited. Toward the southwestern boundary the dip is broken by a series of branching faults of the Simms Mountain fault zone. Branching faults from all of the bounding zones of faulting extend into, and most of them die out within, the structural block. Several of these faults have been mapped at the surface and others that are not mapped at the surface have been discovered in the underground workings. The predominant northwest trend of the major structural features is reflected by these branching faults.

The detailed work of Buckley[129] on the joint system in the

129 E. R. Buckley, Geology of the Disseminated Lead Deposits of St. Francois and Washington Counties, Missouri Bureau of Geology and Mines, 9: Part 1, 1908.

Flat River structural block records the strike of prominant joint sets. In decreasing prominence the joint sets strike between:

N. 54° W. and N. 83° W.

N. 16° E. and N. 45° E.

Two joint sets of nearly equal prominence strike:

nearly N.-S.

between N. 70° W. and E.-W.

These joint sets have the following angular relationship to the predominant trend of the major structural features:

nearly parallel,

roughly at a right angle; about 100°.

at an acute angle of about 60°,

at an acute angle of about 30°.

Fractures in the structural block do not seem to have the striking relation to the irregularities on the basement rock surface that is shown elsewhere in the mining district, although the presence of knobs and ridges that protrude into the Bonneterre formation attest to the irregularity of this surface. The lack of relation of fracturing to the knobs and ridges may be due to a low relief on the basement rock surface because a low relief would permit less variation in thickness of the sediments, thereby reducing their tendency to fracture. However, little is known about the relief on the pre-Cambrian surface in the structural block. The Lamotte formation is thicker here than in the Fredericktown area, and it may have effectively reduced the relief of the surface upon which the Bonneterre formation was deposited by filling the depressions on the basement rock surface. Therefore, although the relief on this surface may not be less than elsewhere in the mining district, its influence on fracturing would be minimized just as effectively. The control of fracturing by the basement rock projections may be masked by the prominent fracture system formed by the deformation that produced the structural block. Detailed observations throughout the mines would be necessary to establish this possibility, but such detailed mapping is beyond the scope of this study.

This structural environment consists of a section of the crust within which the sediments are broken by an extensive meshwork of fracture planes. The direction of the regional dip has been reversed by the deformation which has tilted the strata. In the downdip direction the structural block is bounded by zones of faulting, and in the updip direction it is bounded by an anticlinal uplift. These conditions constitute the environment exemplified by the Flat River structural block.

Structural Block Type Lead Ore Body

The structural block type lead ore body is exemplified by the well known disseminated deposits in the Flat River-Bonne Terre area. Fifty-one mines have been developed in this type. The important ore mineral is galena, and associated sulphide minerals include marcasite, pyrite, chalcopyrite, siegenite, and sphalerite. Non-sulphide gangue minerals are dolomite, calcite, and quartz. Several secondary minerals have been reported from deposits of this type.[130]

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130 W. A. Tarr, "Origin of the Southeast Missouri Lead Deposits," Economic Geology, 31:745, 1936.

The modes of occurrence of the mineralization are the same as those observed in the knob and ridge type lead ore body. The major part of the mineralization in the structural block type lead ore body is the disseminated mode of occurrence, in contrast to the knob and ridge ore body. Bedding plane, fracture filling, and cavity filling types of mineralization increase at the upper and lateral margins of the large disseminated bodies. Buckley[131] pointed out the

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131 Buckley, op. cit., pp. 95, 108, 138, and 139.

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variations toward the margins of the ore bodies in his descriptions of the mineralization in the structural block. In the Federal Mine

No. 1:

> The ore body in this mine is characterized by extreme irregularity, being especially bunchy in the upper level...In the lower level the ore body exhibits greater regularity...

In the Federal Mine No. 5:

> In the 210 foot level...the ore occurs more in bunches than in the 333 foot level...it may be observed that in general the ore body at the upper level is much more irregular and bunchy than at the lower level.

In the St. Louis Smelting and Refining Company Mine No. 4:

> Galena and calcite, filling or lining the walls of joints, are common at both levels (262 and 327 foot levels), although probably more numerous at the upper level.

Also:

> There is nothing unusual in these occurrences, they have been observed in many of the other mines.

The structural block type lead ore body has been found only in the Bonneterre formation, and although the stratigraphic position is variable, the largest production has come from the lower half of the formation. The ore bodies, in general, are horizontal and follow a given series of beds, but there are some stopes in which the ore is distributed vertically through 200 feet or more. At a few places ore extends within a few feet of the overlying Davis formation. The ore is not of uniform tenor throughout this height. The ore bodies at the lower levels are more persistent than those at the upper levels.

At the Doe Run Mine No. 11 the main mineralization was found in a "core" extending vertically through 200 feet. In the core, the mineralization is predominantly disseminated and the intensity visibly decreases upward and toward the margins of the ore body. Bedding plane mineralization predominates at the edges of the core and near the upper margin. A similar relationship is evident at the National Mine No. 7.

Ore bodies of large vertical extent are in the minority in the structural block. In the majority of the mines the mineralization is confined to a zone 20 to 30 feet thick and 20 to 50 feet above the base of the formation. This stratigraphic position varies and more than one level may be present. At the Federal Mine No. 12, one ore body is 25 feet above the base of the Bonneterre; it has a vertical range of 20 to 25 feet, a width of several hundred feet, and a length of more than 1000 feet. Another ore body occurs at a higher stratigraphic position, but it is smaller.

A directional trend is evident from the plan outline of many, but not all, mines. A mine consisting of more than one level may exhibit an alignment on one level and the one above or below it may show either a similar trend, a different trend, or no directional trend at all. If the ore bodies are viewed as a unit, a northwest alignment along possibly three parallel lines is noticeable. The lack of alignment of the ore bodies is apparent only when the field of view or consideration is narrowed to either individual ore bodies or to small groups of ore bodies. The northwest trend of the ore bodies coincides with the structural grain and suggests the interrelationship of ore bodies and fracturing.

The extended vertical range of mineralization; the size, form, and continuity of the ore bodies; and the predominantly disseminated mode of occurrence are differentiating features of this type of lead ore body.

CHAPTER V

STRUCTURAL CONTROLS EFFECTIVE IN LOCALIZING THE SOUTHEASTERN MISSOURI MINING DISTRICT

The coincident positions of the mining district and the area of most intense deformation by faulting in southeastern Missouri region is a marked relationship. The nearly universal association of faulting with epigenetic ore deposits is the basis for assuming that this structural deformation is one of the basic reasons for the location of the district. The objective is to show the relation of the mining district to the structural conditions which make its position favorable for the formation of ore deposits.

Diastrophism in the mining district, in the Ozark uplift region, and elsewhere in Missouri, furnishes clues to the structural history of the area. Some geologic data are necessary for an interpretation of the deformation. These data are presented in the following order:

1. Regional structural trends.
2. Variation in intensity of crustal reaction.
3. Fault pattern.
4. Thickness of the sedimentary veneer.
5. Characteristics of sedimentation.
6. Folding.
7. Jointing in the areas of ore deposits.
8. Age of the deformation.

FIGURE 28

Major Structural Trends in the Eastern Missouri Region

Regional Structural Trends

The alignment of structures forms regional structural trends which are the result of crustal reaction to regional stresses. They are recognized by the alignment of structural features which are revealed by detailed geologic mapping, by reconnaissance survey, and by drillhole data. The trends in eastern Missouri, Figure 28, are generalized. The local deviation of structures from the regional trend corresponds to local modifications of the regional stresses. The present attitude of the crust is due to a combination of stresses that have been applied to the mining district, and to a larger surrounding area. It may have been produced by a combination of forces acting in several different directions at various times, or the stresses may have been concurrent, and, if so, they can be represented by a resultant which would produce the same net result as the combination. Applied or deforming stress in the following discussion refers to a resultant, although more than one period of deformation is recognized in the mining district.

One regional structural trend is indicated by the Lincoln Fold in Lincoln, Pike, and Ralls counties, where its position is marked by outcrops of Ordovician, Silurian, and Devonian strata bordered by outcrops of Mississippian strata. The reentrant of Mississippian into Pennsylvanian strata in Marion, Shelby, and Knox counties, and data from drillholes in Adair and Putnam counties suggest an anticlinal structure which extends the trend into Putnam County. It has a length of 165 miles in Missouri.[132]

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132 H. S. McQueen, N. S. Hinchey, and Kenneth Aid, "The Lincoln Fold in Lincoln, Pike, and Ralls Counties, Northeastern Missouri." Kansas Geological Society, Guide book, 15th Annual Field Conference, 1941. P. 100.

Another trend can be traced by inliers of Ordovician strata northwestward through Jefferson and St. Louis counties and into St. Charles County where it either disappears or is obscure to reconnaissance survey. It apparently is a continuation of the Valmeyer anticline in Illinois,[133] and it has a length of 40 miles in

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133 J. V. Howell, "Tectonic Map of Central United States," Kansas Geological Society, Fifth Annual Field Conference, 1931.

Missouri.

The Ste. Genevieve fault zone marks a regional structure trend that crosses the mining district. It has a known continuous length of more than 100 miles. The trend is projected by irregularly oriented faults eight miles beyond the northwestern extremity of the Ste. Genevieve fault zone, and by an anticlinal warp, indicated by an inlier of the Gasconade formation, an additional 11 miles to the northwest. Although it is not well marked northwestward to the Missouri River, it is manifest in southern Montgomery County from an outcrop of Ordovician and Devonian strata, elongate in a northwest direction, forming a reentrant into the bordering Mississippian strata. The position of the trend shifts slightly southwest where it passes from the area of Ordovician outcrop into the area of Mississippian and Pennsylvanian outcrop. Inliers of Devonian strata in northeastern Callaway County and two large inliers of Mississippian strata in southwestern Audrain and northeastern Boone counties are on the extension of this regional trend. It has been projected from these inliers northwestward into Worth County.[134]

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134 H. S. McQueen and F. C. Greene, <u>The Geology of Northwestern Missouri</u>, Missouri Geological Survey and Water Resources, 2d ser., 25:72-73, 1938.

This regional structural trend consists of a zone of faulting and folding which is expressed by a series of anticlinal and domal features along a distance of 260 miles. Its characteristics typify most of the trends which are marked either by folds, zones of faulting, or by both types of deformation. The dip on the limbs of the folds is less than one degree at many places, and these features are evident only from regional observations. Elsewhere the folds are defined by dips of 30° or more. The linear extent of the trends illustrates the magnitude of the area subjected to the stress and their generally broad, low character indicates the intensity of the stress. The folding reflects mild deformation and indicates the application of a comparatively gentle stress over a large area.

Exposures show that the basement rock is involved in some of the faulting. It was upthrown by movement along the Simms Mountain fault zone into juxtaposition with the Potosi in west-central St. Francois County in T. 36 N., R. 4 E. It is involved also in southern St. Francois County in sec. 29 and 30, T. 35 N., R. 6 E., in secs. 21 and 22, T. 35 N., R. 5 E., and in Madison County in Ts. 33 and 34 N., Rs. 7 and 8 E. Branching faults of the Big River fault zone involve the basement rock in sec. 15, T. 36 N., R. 3 E., just west of Irondale, St. Francois County. The Palmer fault zone cuts the basement rock in Washington and St. Francois counties in T. 35 N., Rs. 3 and 4 E.

Indirect evidence suggests that the basement rock is involved elsewhere along the zones of major faulting. It is not difficult to rationalize that faults involve the buried basement rock where a sedimentary veneer of essentially horizontal strata 1000 feet thick has a stratigraphic displacement of 400 to 600 feet. Along the southeastern portion of the Palmer fault zone, the Lamotte lies against the Derby-Doerun formation. The top of the Lamotte is not present at the fault zone, but the minimum stratigraphic displacement in this locality is more than 500 feet, which is more than the greatest known thickness of the Lamotte; therefore, the basement rock must have been involved in the faulting. Other examples from localities throughout the mining district could be given and all would point to the conclusion that the major zones of faulting cut the basement rock. Thus the basement must have been subjected to stress.

Figure 28 shows the northwest strike of the regional structural trends. If it can be assumed that the resultant stress was relieved by the anticlinal warping chiefly perpendicular to the direction from which the stress was applied, the northwest strike indicates a stress application from either a northeast or southwest direction.

The regional structural trends suggest, 1) by their characteristics, the intensity of the applied stress, 2) by their linear

FIGURE 29

Known Distribution of Deformation by Faulting to the
Southwest of the St. Francois Mountains

extent, the magnitude of the area subjected to the stress, 3) by the partial resolution of the stress in the basement rock, the medium through which the stress was transmitted, and 4) by their strike, that the stress was applied from either a northeast or southwest direction.

Variation in Intensity of Crustal Reaction

The variation in intensity of crustal reaction with geographic locality is reflected by the structural features. The best means available to determine the structural attitude of the basement rock where it is not exposed is by its reflection in the overlying sediments. West of the St. Francois Mountains the sediments are warped into a series of gentle folds which have a northwest trend and are broken by widely spaced zones of faulting. Bridge[135] was unable to

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135 Josiah Bridge, Geology of the Eminence and Cardareva Quadrangles, Missouri Bureau of Geology and Mines, 2d ser., 24: 1930.

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map a single fault in the Eminence and Cardareva quadrangles which are situated 45 miles southwest of the St. Francois Mountains. The nearest known fault zone in this direction is 120 miles from the mining district and the next one is an additional 50 miles southwest. This wide spacing is typical of fault zones southwest of the structural apex of the Ozark uplift (see Fig. 29).

Northeast of the St. Francois Mountains but still in Missouri, the structure consists of closely spaced zones of intricate faulting, and local folding. The deformation northeast of the St. Francois

Mountains compared to that to the southwest, reflects the variation in intensity of crustal reaction to the stress. The Southeastern Missouri mining district contains the most intense deformation associated with the structural apex of the Ozark uplift.

Fault Pattern

The district-wide fault pattern is one of sub-parallel fault zones and a connecting cross fault zone. The individual fault zones are composed of a series of parallel, sub-parallel, and branching faults. Both normal and reverse faulting have been recognized in the district. Reverse faulting and overturned beds have been mapped in the Ste. Genevieve fault zone but is not known throughout its entire length. The Ste. Genevieve fault is a zone of normal faulting northwest of the point of intersection with the Big River fault.

The Big River fault zone has an en echelon pattern, indicated by the relation of the strike of the individual faults to the strike of the fault zone. The strike of fracture cleavage in relation to the strike of the individual faults indicates a horizontal component of movement. The northwest side of the fault has moved differentially northeastward. The fact that reverse faulting disappears from the Ste. Genevieve fault zone at its juncture with the Big River fault zone, and that horizontal movement has occurred along the Big River fault zone suggests a relationship between the two.

The reverse faulting aids in establishing the direction from which the deforming stress was applied. The direction of overturn of the beds, and the dip of the low angle reverse fault planes indicate that the stress was directed from the southwest toward the northeast. The more probable source for the stress to the southwest of the Ozark uplift, concluded from known deformation in that direction, and the fact that the relatively stable area of the North American continent is toward the northeast is indirect evidence substantiating the conclusion that the stress came from the southwest.

Flint concluded from a study of the reverse faulting and overturned beds in Perry and Cape Girardeau counties, which lie to the east of the mining district, that "The main thrust was directed toward the northeast, normal to the strike of the faults."[136] Hager

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136 R. F. Flint, "A Report on the Geology of Parts of Perry and Cape Girardeau Counties," (unpublished manuscript, Missouri Geological Survey and Water Resources, Rolla, 1925).

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states that "...northwest folds found on the Ozark uplift undoubtedly come from a push from the south-southwest,..."[137]

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137 Dorsey Hager, "Tectonics of North-Central States," Bulletin of the American Association of Petroleum Geologists. 33: 1198-1205, 1949.

Thickness of the Sedimentary Veneer

The thickness of the sedimentary veneer is a factor to be considered in connection with the deformation in the mining district. The possible maximum thickness of sediments which may have covered the Ozark uplift region can be estimated only. The present sedimentary cover is comparatively thin; at most places in Missouri it does not exceed 5000 feet and at some places in the mining district sediments are absent. The sedimentary units thin from all directions toward the St. Francois Mountains and this thinning and the erosional breaks in the stratigraphic section preclude an aggregate thickness in the area comparable to their aggregate thickness in surrounding regions.

Jumbled blocks of strata of Silurian and Devonian age are preserved in downfaulted blocks[138] near Marble Hill, Bollinger County, about 24 miles southeast of Fredericktown, Madison County. Rocks with Devonian fossils are present in the diatremes distributed over the south nose of the Farmington anticline. Strata of Silurian and Devonian age are preserved in the grabens in the Ste. Genevieve fault zone. These occurrences suggest the former presence of Silurian and Devonian rocks in the mining district. However, immediately north of the Ste. Genevieve fault zone, the Silurian and Devonian are absent and the Mississippian lies directly on the Ordovician. The Devonian rocks involved in the diatremes are not believed to have been erosional remnants. The diatremes are 2500 feet higher structurally than the Mississippian-Ordovician contact north of the Ste. Genevieve fault zone. It appears unlikely that erosional remnants of the Devonian strata would exist 2500 feet higher than where these strata were removed by erosion. This reasoning shows that the Silurian and Devonian were removed prior to the deposition of the Mississippian strata except where they were preserved in fault blocks and diatremes.

138 Robert L. Heller, "Geology of the Marble Hill Area, Bollinger County, Missouri," (unpublished master's thesis, University of Missouri, Columbia, 1943). Pp. 62 and 103.

Beds of Devonian age are present between strata of Ordovician and Mississippian ages along the Missouri River about 50 miles northwest of the mining district. Approximately 35 miles east of the mining district and north of Cape Girardeau, Missouri, strata of Silurian and Devonian ages are in their normal position above rocks of Ordovician age.

Mississippian strata of Meramec age are overlain by Pennsylvanian strata in western Missouri. Younger Mississippian is present in southwestern Missouri and along the east-central border of the State.

Pennsylvanian beds of Atoka age in the Cherokee Basin to the west have not been identified in Missouri. In the northwestern corner of, and northwest beyond, the mining district the Pennsylvanian strata rest directly on Ordovician rocks. This Pennsylvanian overlap is discussed by Dake.[139]

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139 C. L. Dake, "Basal Pennsylvanian Transgression in the Ozarks," Bulletin of the Geological Society of America, 46:697-714, 1935.

These examples demonstrate why the aggregate thickness of the sediments in the mining district is not comparable to the aggregate thickness in surrounding regions. For example, before the Mississippian strata were laid down in the mining district, certainly the Silurian and Devonian and possibly some Ordovician rocks were removed. Likewise, before the Pennsylvanian sediments were deposited, the Mississippian beds were removed from large areas. Similar relationships for the stratigraphic sequence within systems also indicate that the sedimentary cover on the basement rock in the mining district was always relatively thin.

Spurr[140] estimated the former thickness of the sedimentary

140 J. E. Spurr, The Ore Magmas (New York: McGraw Hill Book Company, 1923). P. 411.

cover in the mining district to be 5000 feet. Brown[141] accepts

141 J. S. Brown, Ore Genesis (New Jersey: Hopewell Press, 1948). P. 169.

Spurr's estimate, although he says 10,000 feet is possible and 15,000 feet could have existed. The estimate of 5000 feet may be too high in consideration of the thinning toward the mining district and the erosional breaks in the stratigraphic section. The writer's opinion is that the thickness of the sedimentary cover in the area of the ore deposits probably never exceeded 4000 feet, and it is likely that 3000 feet was a maximum. Regardless of the specific thickness, all estimates agree that the sedimentary cover was comparatively thin.

A thin sedimentary cover on the basement rock and the consequent limited capacity of the sediments to transmit stresses substantiates the previous implication that the deforming stress was propagated largely through the basement rock.

Characteristics of Sedimentation

The lithologic characteristics of the sediments in connection with their stratigraphic relations aid an interpretation of the geologic history of the Ozark uplift region. While the Lamotte formation was being deposited an elongated landmass existed at the approximate position of the St. Francois Mountains. This area remained positive during the deposition of the conformable series of Upper Cambrian sediments. The characteristics of sedimentation and stratigraphic relations of the Elvins group as interpreted in this report modify some interpretations of the early diastrophic events in the Ozarks made by Dake and Bridge.[142] The thinning of the sedimentary units toward the mining district suggests that the Ozark uplift region generally has maintained an elevated position throughout geologic time, except for occasional periods of depression. Therefore, it is probable that at the time the deforming stress was applied the area was high.

142 C. L. Dake and Josiah Bridge, "Early Diastrophic Events in the Ozarks," _Bulletin of the Geological Society of America_, Abstract, 38:157-158, 1928.

Folding

The absence of close folding is one of the most striking features in the southeastern Missouri region. Most of the sharp flexures are either relatively small in magnitude, due to local conditions, or local structures associated with regional features. On the other hand, the regional folding consists of mostly broad, low warping marked by dips which are commonly less than one degree.

The sharp flexures are either fault drag folds, solution flexures, initial dip, or steeply dipping limbs of anticlines along the regional structural trends.

Jointing in the Areas of Ore Deposits

Buckley[143] made an extensive study of the jointing in the Flat

143 E. R. Buckley, Geology of the Disseminated Lead Deposits of St. Francois and Washington Counties, Missouri Bureau of Geology and Mines, 2d ser., 9:78, 1908.

River structural block. He found that the most abundant joint set strikes between N. 54° W. and N. 83° W., and the next most abundant set strikes between N. 16° E. and N. 45° E. They are related to the strike of the regional structural trends in the following manner:

1. The most abundant set is nearly parallel to the average strike of the regional structural trends.
2. The next most abundant set is nearly at a right angle to the average strike of the regional structural trends.

Buckley also recognized two less prominent joint sets. One set strikes nearly north and the other strikes N. 70° W. to west. Their strike forms angles of 60° and 30° respectively with the strike of the regional structural trends.

The angular relationship of the joint sets in the Fredericktown area to the average strike of the regional structural trends is almost the same as that in the Flat River structural block. Because of their diverse directions of strike, the joints directly related to the knobs and ridges on the basement topography cannot be compared to the regional structural trends. Those joints resulting from stresses of a regional character strike N. 15° E. to N. 40° E., N. 45° W. to N. 70° W., north, and east, in order of their prominence.

In the vicinity of Annapolis, Iron County, the joint system consists of joint sets which strike N. 60° E. to N. 80° E., N. 10° W. to N. 40° W., N. 70° W. to N. 80° W., and N. 15° E. to N. 35° E. They have an angular relationship to the regional structural trends similar to that in the Flat River structural block and the Fredericktown area.

The similar orientation of the joint systems in widely separated areas within the mining district suggests that the pattern of the regional jointing may be related to a common deforming stress.

Age of the Deformation

The age of only some of the structural features can be determined accurately. The relation of a few structures to each other indicates the sequence of development, although their specific age is unknown.

Weller and St. Clair[144] recognized two distinct periods of movement in the Ste. Genevieve fault zone. The earlier period is post-Middle Devonian and the later period is post-Pennsylvanian. Some of the other zones of faulting cannot be dated more accurately than as post-Upper Cambrian, post-Lower Ordovician, etc., because only lower Paleozoic formations are present over a large portion of the mining district.

The relative age of the Berryman, the Palmer, the Big River,

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144 S. Weller and S. St. Clair, Geology of Ste. Genevieve County, Missouri, Missouri Bureau of Geology and Mines, 2d ser., 22:256-266, 1928.

and the Simms Mountain fault zones can be ascertained. The Berryman fault zone and the faulting to the northwest (Leasburg fault zone) probably are correlative. The relative movement, the amount of displacement, and their trends indicate that they may be one continuous zone of faulting. Pennsylvanian beds, in the northwest corner of the mining district, involved in this faulting indicate that the Leasburg fault zone was active in post-Cherokee time. If the Berryman fault is a continuation of the Leasburg fault, then it also had post-Cherokee movement.

The age relationship of the Berryman and Palmer fault zones is indicated by that segment in sec. 30, T. 37 N., R. 1 W., which was involved in the movements along both the fault zones. The strata on the north side were upthrown 200 feet by movement along the Berryman fault and later were downthrown 300 feet by movement along the Palmer fault. The difference in the magnitude of the two movements is 100 feet which is equal to the amount of vertical displacement along this segment of the fault. The Palmer fault zone exhibits 300 feet of stratigraphic displacement east of this segment, but there is no indication of folding along a westward projection of its strike. The abrupt termination of the Palmer fault zone where it exhibits 300 feet of vertical displacement and the absence of folding along its projected strike, suggest that the Berryman fault zone was preexistent.

The Big River fault zone terminates abruptly at the Palmer fault zone in sec. 26, T. 36 N., R. 2 E., suggesting that the Palmer fault zone is older. Similarly, the Simms Mountain fault terminates at the Big River fault zone in sec. 9, T. 36 N., R. 3 E. Its abrupt termination indicates that the Big River fault is older.

The actual time of faulting cannot be determined, but the sequence of their development is evident. The Berryman fault zone is the oldest of the four and it may have been active in post-Cherokee time. The Palmer fault zone is the next oldest, and it is followed in order of development by the Big River and the Simms Mountain fault zones.

Fossiliferous rocks in the diatremes prove that the igneous activity is not older than Middle Devonian, because it must have occurred in post-Middle Devonian time to have involved these strata. Regional stratigraphic relations indicate that these rocks were removed from the area of the diatremes prior to Mississippian deposition. Thus, they could not have been involved in igneous activity occurring after the beginning of Mississippian time. Therefore, the igneous activity which produced the diatremes took place in the interval of time between the Middle Devonian and the Mississippian. The same line of reasoning narrows the time interval still more. the diatremes are younger than Middle Devonian and older than the erosional period that removed these strata.

High-angle tensional faulting was prevalent in the Ste. Genevieve fault zone during the early period of movement which is post-Middle Devonian and pre-Mississippian in age. The corresponding age of the faulting and the igneous activity suggests that they are directly related. The diatremes on the south nose of the Farmington anticline and its increase in width southward suggest that the

Farmington anticline originated during the period of igneous activity.

The Geological Map of Missouri, 1939, indicates that the direction of some of the regional structural features was determined in pre-Mississippian time. South of Booneville, in Cooper County, and in Moniteau County, strata of Mississippian age rest directly on Ordovician rocks. To the east and west, Devonian rocks lie between the Ordovician and Mississippian strata.

Rubey[145] stated that the uplift responsible for the Cap au Gres faulted flexure (Lincoln Fold in Missouri):

> ...began with gentle warping in Silurian time, continued intermittently through the Devonian and Mississippian, culminated in sharp folding before Pennsylvanian, and waned with minor faulting or folding after Pennsylvanian, again after late Tertiary, and possibly continuing into historic time.

According to McQueen, Hinchey, and Aid,[146] the geologic record of the Lincoln Fold gives no evidence of pronounced regional folding prior to Silurian time. Regional movement in the present area of the fold probably occurred at the end of Silurian time, and after Devonian deposition the axis of the fold was rejuvenated. The fold reached its maximum structural development near the close of the Mississippian. Faulting may have occurred between Mississippian and Pennsylvanian time, but the late history of the fold is obscure due to the absence

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145 W. W. Rubey, "Structural History of the Cap au Gres Faulted Flexure, Illinois," *Bulletin of the Geological Society of America*, Abstract, 41:52-53, 1930.

146 McQueen, Hinchey, and Aid, *op. cit.*, pp. 100-110.

of the younger Pennsylvanian beds.

Structure maps by Hinds and Greene[147] and McQueen and

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147 Henry Hinds and F. C. Greene, The Stratigraphy of the Pennsylvanian Series in Missouri, Missouri Bureau of Geology and Mines, 2d ser., 13:Plate 23, 1915.

Greene[148] drawn on datum planes in the Pennsylvanian show the same

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148 H. S. McQueen and F. C. Greene, The Geology of Northwestern Missouri, Missouri Geological Survey and Water Resources, 2d ser., 25:Plate 1, 1938.

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regional structural grain as that indicated in pre-Mississippian time. All the regional structural features cannot be dated as pre-Mississippian although the directional pattern of later features may have been established at an earlier time.

SUMMARY

The voluminous literature concerning the Southeastern Missouri mining district contains little information about the processes which contributed to the deformation. Broadhead thought that the Ozark Mountain building may have resulted from "...forces acting at different places upon a broad or flat surface forming a massive anticlinal, breaking off into a monoclinal around the margin."[149]

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149 G. C. Broadhead, "Geologic History of the Ozark Uplift," American Journal of Science, 42:6-13, 1889.

Haworth[150] visualized the Ozark uplift as a monoclinal type of

150 Erasmus Haworth, "Relations between the Ozark Uplift and Ore Deposits," Bulletin of the Geological Society of America, 11: 231-240, 1900.

structure, and he believed that the forces acted radially rather than tangentially, stretching the strata rather than crumpling them.

Giles[151] used the term geanticline in describing the Ozark

151 A. W. Giles, "Structural Features of the Mississippi Valley Region and Their Relation to Mineralization," Edson S. Bastin, editor, Contributions to a Knowledge of the Lead and Zinc Deposits of the Mississippi Valley Region, Geological Society of America, Special Paper No. 24, 1939. P. 44.

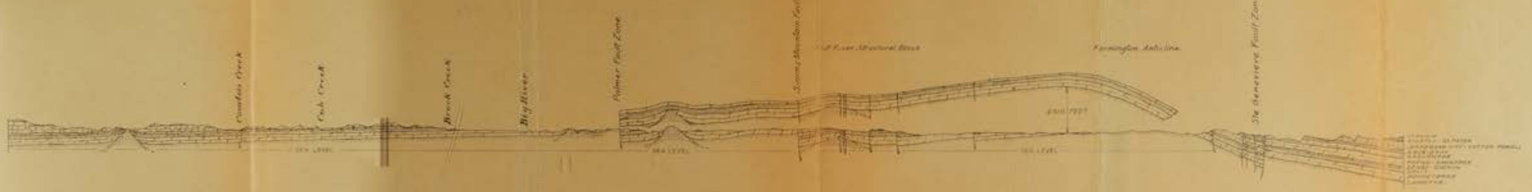
uplift.

Spurr explains the deformation in the mining district, particularly the Ste. Genevieve fault zone, thus:

> Such a crustal sinking as shown by this southeastern Missouri fault graben or ditch, signifying a collapse of a section of the crust due to local sinking of the foundation support, can hardly be explained except by failure of competency of an underlying fluid foundation -- that is to say, an underlying supporting magma on which the crust floats or floated;...[152]

152 J. E. Spurr, "The Southeast Missouri Ore-Magmatic District," Engineering and Mining Journal, 122:968-975, 1926.

An attempt to reconstruct the structural history is hampered by the incomplete geologic record. The effect of gentle warping during and at the close of Silurian time is not recognizable in the mining district because of the absence of Silurian strata, except in areas structurally favorable for their preservation. The geologic record does not reveal noteworthy diastrophism prior to post-Middle Devonian time.



STRUCTURE SECTION A-A'

SHOWING POSITION OF SEDIMENTS BEFORE AND AFTER FAULTING

HORIZONTAL SCALE 1" = 2 MILES
VERTICAL SCALE 1" = 2000 FEET

After Middle Devonian, but before Mississippian time, magmatic pressure caused explosive blowouts through perhaps 4000 feet of sediments.[153] Upfolding and tensional faulting attended this period of

153 A. L. Kidwell, Post-Devonian Igneous Activity in Southeastern Missouri, Missouri Geological Survey and Water Resources, Report of Investigations No. 4, 1947. P. 30.

deformation. The Farmington anticline originated and was broken axially at the north end by high angle tensional faulting. Silurian and Devonian strata were downfaulted in the Ste. Genevieve fault zone. Spurr's idea of failure of competency of an underlying fluid foundation which permitted the crustal sinking shown by the downfaulted blocks in the Ste. Genevieve fault zone, gains strength now that an incompetency is indicated for this region at the time the crustal sinking occurred.

If collapse was a factor in this individual structural feature, it also may have been a factor on a larger scale. Magmatic pressure could have caused the arching that formed the Farmington anticline, and, in addition, it could have raised the Ozark region. The specific age of most of the tensional faults is not known and they may have originated during the period of igneous activity.

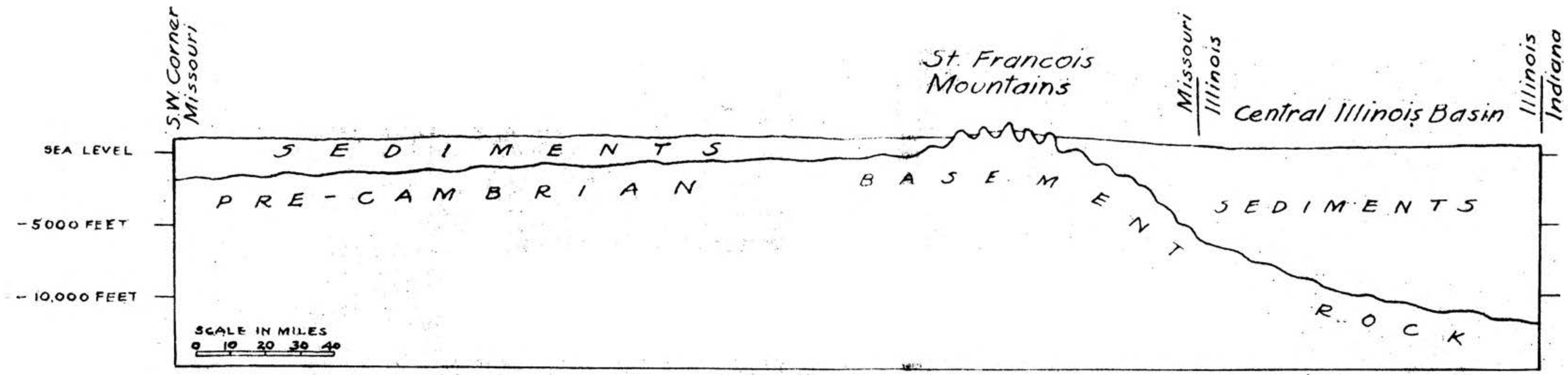
The cross-section in Figure 30 is drawn on a line nearly normal to the regional structural trends. If the regional dip is projected and the faulting is eliminated, the sediments in the vicinity of the Farmington anticline would be essentially 2100 feet above their present position. The projection of the regional dip on the eastern and western flanks of the Ozark uplift indicates that the maximum difference in present and restored positions of the sediments is slightly west of the crest of the Farmington anticline. The different character of the Ste. Genevieve fault zone where it borders the Farmington anticline possibly could be explained by hinge action which occurred as the sediments to the west were dropped.

If the mechanics of upthrust as explained by Willis[154] produced the tensional faulting pattern, the relative movement along the fault zones indicates that the intensity of the upthrust at the Farmington anticline was less than that to the west. However, the explosive blowouts on the southern nose of the anticline indicate high magmatic pressure.

154 Bailey Willis, Geologic Structures, (New York: McGraw-Hill Book Company, 1923). P. 45.

Collapse as a factor influencing the pattern of deformation cannot be ruled out, although its influence can be only speculative. A downward settling of the crust following pressure release does not seem to be an unreasonable hypothesis. A possible sequence of events may have originated with the build up of magmatic pressure producing uplift of the Ozark region and local upfolding at the position of the Farmington anticline. The explosive blowouts occurred probably near the time of maximum pressure exerted by the magma. Subsequent release of support produced a low pressure chamber and a downward adjustment of the crust followed. Tensional faulting may have taken place either at the time of the uplift, or at the time of the downward adjustment, or possibly at both times.

The mining district in either late or post-Pennsylvanian time,



DIAGRAMMATIC CROSS-SECTION SHOWING

THICKNESS OF THE SEDIMENTARY VENEER

was subjected to compressive stress which, in part, acted tangentially to the surface. The force was applied over a large area and propagated through the basement rock from a southwest direction. It produced reverse faulting in the Ste. Genevieve fault zone, the en echelon pattern of the Big River fault zone, and movement along the Berryman fault. Folds with their axes perpendicular to the Simms Mountain fault zone may be the result of this stress. The high angle tensional fault that cuts the north end of the Farmington anticline was subjected to movement opposite in direction to that which first produced it. The later movement was not as great as the earlier, but drag folds which dip toward the fault were developed on the downthrown side. Movement probably occurred at this time along all the zones of faulting in the area.

The greater thickness of the sedimentary cover northeast of the structural apex of the Ozark uplift is visualized as a factor causing the more marked deformation by compressive stress in that area. Figure 31 is a diagrammatic cross-section extending northeastward from the southwest corner of Missouri through the St. Francois Mountains to the Illinois-Indiana boundary. The thin sedimentary cover on the west flank of the Ozark uplift is in sharp contrast with the abrupt thickening of the sediments on the east flank, where it reaches a thickness of nearly 12,000 feet in the Central Illinois Basin.[155] The aggregate thickness of the sediments

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155 L. E. Workman and A. H. Bell, "Deep Drilling and Deeper Oil Possibilities in Illinois," Bulletin of the American Association of Petroleum Geologists, 32:2041-2063, 1948.

throughout the Paleozoic was greater in the Central Illinois Basin than on the Ozark uplift.

The sediments on the western flank of the Ozark uplift had a limited capacity to carry the deforming stress because they consist of a thin veneer superimposed on a stronger mass, and their reaction to the stress was influenced by the strength of the basement rock. Therefore, the deformation of the sediments conforms to the yielding of the basement rock. The gentle arching and the widely spaced faulting west of the structural apex of the Ozark uplift may reflect the control exerted by the strong basement rock.

The steep contact between the basement rock and the sediments on the east flank of the Ozark uplift and the thick sedimentary cover in the Central Illinois Basin constitute a markedly different geologic environment from that prevailing on the west flank. The stress was transmitted from the southwest probably in a large part through the basement rock. At the steep contact, the stress would be transferred from the basement rock to the thick sediments, and they could carry a greater proportion of it than the thin sediments. Also the thick sediments would be influenced less by the strong basement rock and they could react to the stress in accordance with their own ability to withstand it. The lesser competency of the sediments, due to the decreased influence of the basement rock, and the greater stress transferred to them could combine to produce the marked deformation by compressive force northeast of the structural apex of the Ozark uplift. This deformation coincides with the position of the steep contact between the basement rock and the sediments and the abrupt thickening of the sedimentary cover.

CHAPTER VI

STRATIGRAPHIC AND STRUCTURAL POSSIBILITIES FOR THE FUTURE EXPANSION OF THE MINING DISTRICT

The area of mining in the Southeastern Missouri mining district must continuously expand if the present rate of production is to be maintained. There are several methods of approach toward extending it, but this report is concerned primarily with the possibility of finding new areas containing ore bodies. The factors of a suitable host rock, the presence of mineralizing solutions, and favorable structural environments are involved in a search for these areas. The favorable host rock is arrived at empirically; the presence of mineralizing solutions is indicated by the presence of ore minerals; and the structural environments are determined from detailed mapping and drilling.

The present stratigraphic and structural possibilities for the future expansion of the mining district must be evaluated with the limitations of available geologic data in mind. The geographic distribution of host rocks is important. In addition, the possibility that strata not normally considered favorable may become so under some conditions must not be overlooked. The information pointing to these conditions is presented later. Further study may discover other structural environments which localize ore bodies, and future exploration may expand the area in which the presence of mineralizing solutions is indicated. Mining may be extended potentially both vertically and laterally.

Distribution of Favorable Host Rock

The most favorable host rock is the Bonneterre and the present production comes from this formation. Strata both older and younger than the Bonneterre formerly yielded ore. A small volume of ore has been obtained from the Lamotte formation, and the important production in the early history of the mining district came from mines at or near the Potosi-Eminence contact, but some came from formations as young as the Jefferson City.

The geographic distribution of the Bonneterre is a primary consideration because it is recognized as the most favorable host rock. The pre-Cambrian erosional surface had been partly obscured by the Lamotte before the Bonneterre sediments were deposited on the Lamotte and the basement rock where it is higher than the upper level of Lamotte deposition. Some of the knobs and ridges of the basement rock topography extended above the upper level of Bonneterre deposition, however, the Bonneterre was deposited in the valley system across the structural apex of the Ozark uplift. These higher topographic features were covered by younger sediments and erosion subsequently has resurrected many of them, but others still are buried beneath the younger sediments. Wherever younger formations are at the surface, the Bonneterre underlies them, except where it cuts out against the knobs and ridges of the basement rock. Erosion has completely removed the Bonneterre in some areas, and has exposed the Lamotte or the basement rock. The geographic distribution of the

Bonneterre is controlled by the configuration of the basement rock surface and the present erosional surface.

The geographic distribution of younger strata, which are favorable host rocks in some areas, is subject to controls similar to those influencing the distribution of the Bonneterre. However, the influence of the configuration of the basement rock diminished as more of the knobs and ridges were buried by successively younger strata. In general, the formations form roughly concentric outcrop belts around the central igneous mass which marks the structural apex of the Ozark uplift, but the ideal concentric outcrop pattern has been modified by subsequent deformation. The oldest formation occupies the innermost outcrop belt and successively younger formations crop out farther from the structural apex. The older formations underlie younger sediments except where they are overlapped because of hills on the basement rock surface.

Presence of Mineralizing Solutions

The distribution of mines and prospects (Fig. 34) is a clue to the size of the area in which mineralizing solutions have been active. This area is delimited by mineralization in all favorable strata. Mines and prospects beyond the limits of the accompanying maps indicate that this area is greater than that included on the maps. The area delineated by evidence of mineralizing solutions in the Bonneterre is of primary interest because of the large production from deposits in this formation.

The writer knows of the presence of ore minerals in the Bonneterre in widely separated localities in the district. The northernmost occurrence is in T. 38 N.; the southernmost is in T. 31 N.; the westernmost is in R. 1 E.; and the easternmost occurrence is in R. 7 E. The region thus outlined is about 45 miles in a north-south direction, about 40 miles in an east-west direction, and includes about 1800 square miles. In this area, outcrops of rocks older than the Bonneterre constitute approximately 500 square miles, and the Bonneterre is present in about 1300 square miles. Less than perhaps 100 square miles have been tested for mineralization in the Bonneterre, and much of this area has not been tested thoroughly. Although it can not be expected that the Bonneterre will be mineralized throughout the 1300 square miles, it may reasonably be expected that some mineralization may be present in areas not yet tested.

Distribution of Favorable Structural Environments

The distribution of the structural environments is of interest because of their relationship to the ore deposits. The records of production establish the structural block type of lead ore body as the most productive, followed in turn by the knob and ridge and the fault zone types.

The structural history of upfolding, upfaulting, and downfaulting which produced the structural block environment is not recognized at any other place within the mining district. The vertical and horizontal differential movements which resulted from the tilting and twisting to which the structural block was subjected produced abundant fracturing and faulting within it. Much of this fracturing and faulting is recognizable only in the mines, however, the major manifestations of the structural block deformation are discernible from surface observations. Underground observations are not possible in many other areas, but no exact counterpart of the major features of the structural block deformation have been recognized elsewhere in the mining district.

The closest approach to the pattern of deformation in the Flat River structural block perhaps is an area in west-central Washington County. The chief parallelism between the two areas is the sequence of development of bordering zones of faulting and the direction of the differential movement. The sediments in the northern and northwestern portion of the Flat River structural block were raised by movement along the Big River fault, and later activity along the Simms Mountain fault zone dropped them in the southern and southwestern portion. The sediments in the northwestern portion of the Washington County area were raised by movement along the Berryman fault, and they were later downfaulted in the southern portion along the Palmer fault zone.

The folding expressed by the Farmington anticline has no counterpart in the Washington County area. Field observations indicate more extensive fracturing in the Flat River structural block. The structural block is nearly enclosed by boundary structural features, but the Washington County area is not. There is a stratigraphic difference of approximately 1000 feet between the surface formations in the two areas. However, the Bonneterre which is the surface rock over much of the Flat River structural block underlies most of the Washington County area, except in the northern portion where the basement rock crops out as a cluster of knobs and ridges. The basement rock knobs and ridges are buried beneath the sediments in the Flat River structural block. The difference in this structural setting is largely in the surface manifestation, rather than in the actual condition which probably exists at the level of the favorable host rock, i.e., the lower portion of the Bonneterre formation.

The general setting of the knob and ridge structural environment is duplicated at many places in the mining district. It consists of hills on the pre-Cambrian surface surrounded by onlapping sediments and against which the Lamotte sandstone cuts out and is overlapped by the basal beds of the Bonneterre formation. The outcrop pattern (Fig. 32) suggests that these conditions may be present in a belt of varying width on three sides of the central igneous mass forming the St. Francois Mountains. This belt extends from northeastern Madison County, southwestward into northern Wayne County where it turns westward around the southern side of the central igneous mass and extends across southern Iron County. Here it turns northwestward along the southwestern side of the St. Francois Mountains and passes through northeastern Reynolds County, northwestern Iron County, and into southwestern Washington County. The inner margin is marked by the area of non-deposition of the Lamotte sandstone. Within the belt the sediments lie in the buried valley system on the pre-Cambrian erosional surface. The outer margin is marked by the outermost exposed basement rock hills. In addition, an outlying area in west-central Washington County in the vicinity of a cluster of exposed and buried pre-Cambrian knobs and ridges has characteristics that suggest a similar setting.

Float boulders and patches of sedimentary rocks on some of the exposed pre-Cambrian hills indicate that many of these protuberances were once covered by the sediments. Within the belt some buried hills have been discovered by drilling. In sec. 18, T. 40 N., R. 2 W., about one mile west of Sullivan, Franklin County, the Roubidoux formation is at the surface, and the basement rock was encountered in drillholes at depths ranging from 25 to 75 feet. In the center SE$\frac{1}{4}$ sec. 18, T. 32 N., R. 6 E., the basement rock was encountered in a drillhole at a depth of 20 feet. Five hundred feet south and at essentially the same surface altitude, another drillhole encountered the basement rock at a depth of 205 feet. The area delineated on the basis of exposures of the basement rock may contain many knobs and ridges not yet laid bare by erosion. Likewise, the outer margin of the area favorable for the knob and ridge structural environment may be extended and other outlying areas postulated in view of the probable buried knobs and ridges not yet located.

It is estimated that of the approximately 3500 square miles included in the accompanying maps, 1500 square miles, or nearly half of the total area, is favorable for the knob and ridge structural environment.

The fault zone type of lead ore body was the major source of production in the early stages of development of the mining district, however, attention was diverted from it by the discovery of the disseminated ore bodies which were more extensive and amenable to large scale production methods. The fault zone type of lead ore body was important when small scale mining predominated, but there is no production from it today.

As the production from the district declines and the large scale operations cease, the fault zone type of lead ore body once again may become important. Therefore, a review of the possibilities for the fault zone structural environment is desirable.

The fault zone structural environment will be found in association with zones of faulting. Thirteen of the 20 quadrangles included in the accompanying maps have been mapped in detail, and the other seven quadrangles have been covered either completely or partially by reconnaissance surveys. The Simms Mountain fault zone has not been traced to its southeastern extremity. The Black fault zone has not been mapped to the northwest beyond the limits of the accompanying maps. It is doubtful if other unmapped zones of faulting of appreciable magnitude exist, except in those areas where the Potosi and Eminence are the surface formations. Perhaps the most fruitful field of exploration for the fault zone type of lead ore body is along the known zones of faulting. Many ore bodies have been found along these zones and more may exist.

Possibilities for Lateral Extension

The basis for possible lateral extension of mining is discussed in the preceding section. The favorable host rock, the presence of mineralizing solutions, and areas favorable for structural environments are indicated in several hundred square miles of area.

Possibilities for Vertical Extension

The range of occurrence of ore minerals from the Lamotte to the Jefferson City, leaves very few additional strata that may be considered potentially favorable host rocks. However, the meager information now available suggests that the Lamotte may contain more ore than past production from it would indicate.

Sandy dolomite lenses in the Lamotte are known from both surface observations and drillhole data. They have been reported from many places in Ste. Genevieve County, and they have been encountered in drillholes in Washington, St. Francois, and Madison Counties. Lenses have been mined for lead ore in two localities, one in Washington County and one in Ste. Genevieve County. Mineralization occurs in them in another locality.

Information about the Lamotte in the subsurface is limited because of the few penetrations of the formation by drillholes. The small production from the Lamotte and the usual position of ore in the uppermost beds has established the lower limit for most drilling. The majority of the exploratory drillholes cut just enough of the formation to definitely identify the strata. A few wells for water supply extend as much as 100 feet or more into the Lamotte, and some cut the entire formation and are bottomed in the underlying basement rock.

The known localities of lenses are all similarly related to the area of non-deposition of the Lamotte. They are in geographical area (3) (Fig. 2) where an off-shore environment of deposition is indicated. The relation to a definite environment of deposition, which covers considerable area in the mining district, suggests that other localities may exist. How many additional localities may contain mineralized lenses is conjectual.

The sandy dolomite lenses would be susceptible to deformation by the dynamic processes that produce the structural block and fault zone structural environments. The knob and ridge structural environment may affect them, but the slight settling by compaction in a predominantly sandstone section and the limited possibility of alteration of sandstone would probably restrict the effect of the knob and ridge structural environment deformation.

In spite of the meager information now available, the possibilities for downward extension of mining by developing ore in the sandy dolomite lenses in the Lamotte formation, especially in geographical area (3), seem to warrant further investigation.

The strata in the vicinity of mines in the fault zone type lead ore body have been tested at depth in only a few localities. There is little data upon which to base an estimate of the possibilities for downward extension of these mines. The presence of mineralizing solutions was indicated in the Bonneterre formation underlying one area of these mines and, therefore, the possibilities for downward extension must not be ruled out.

CHAPTER VII

SUMMARY

The present study was undertaken to ascertain the structural controls which were effective in localizing the Southeastern Missouri mining district, the structural controls effective in localizing the areas of ore deposits within the mining district, and the effect of the structural controls upon the mode of occurrence of the ore bodies. The nature of the problem necessitated an investigation more inclusive than just structural geology, and accordingly other phases of geology are involved.

The sedimentary succession lies upon a basement of pre-Cambrian extrusive and intrusive igneous rocks. The basement rock was subjected to a long period of erosion which carved a topography with more than 1500 feet of relief prior to the earliest Paleozoic deposition of which we have a record. The sediments were deposited upon this rugged surface.

Deposition of sediments in valleys on the pre-Cambrian erosional surface formed various distinct types of rocks with transitions from one type to another, and caused marked local modifications of the lithology of the lower formations. The feldspathic residuum on the erosional surface was reworked into deposits of conglomerate, arkose, and silty shale, and was incorporated also in other sediments resulting in conglomeratic and arkosic sandstone and calcareous rock. The silty shale formed beds in the Lamotte and Bonneterre formations, and where it did not form beds, its identity is lost. Intercalated beds of arkose in the conglomerate indicate these types of rocks were formed contemporaneously. The vertical and lateral gradations from one type of rock to the other suggest that the arkose was deposited around and over centers of accumulation of the coarse debris. Intercalated beds of arkose and silty shale in the Lamotte and Bonneterre demonstrate contemporaneous deposition with both of these formations. The conglomerate and arkose deposits are associated with the first sediments deposited at any particular locality, and no definite age can be assigned to them.

The association of the calcareous beds of the Bonneterre and the types of rock that were formed from the residuum establishes an area of non-deposition of the Lamotte. It is designated as area 1, 25-30 miles long and 10-12 miles wide, elongated in a northwest direction, with its center a few miles southeast of Ironton, Iron County. This area is surrounded by a second one (area 2) in which the Lamotte is present only in the lower portion of the buried valleys on the pre-Cambrian erosional surface. The two areas are enclosed by a third (area 3) in which the Lamotte is present everywhere except over the highest hills of the pre-Cambrian topography. An outer area (area 4) in which the Lamotte blankets the basement rock surrounds the other three.

Lenses of sandy dolomite in the Lamotte occur in area (3) on the north, northeast, and east sides of the area of non-deposition of the formation. These calcareous lenses apparently formed in an offshore environment of deposition, as a forerunner to the predominantly calcareous deposition which followed during Bonneterre time.

The mining district is associated with the Ozark uplift, the dominant structural element in southeastern Missouri and one of the major elements in the Mississippi Valley region. The district is near the structural apex of the uplift. The apex is marked by the central igneous mass that forms the St. Francois Mountains. Folding and faulting superimposed on the uplift are features establishing the regional structural pattern. Other structures which have produced important modifications of the regional pattern have been recognized in the area. Initial dip is common adjacent to the hills of the pre-Cambrian topography in all types of sediments showing stratification. Solution flexures are widespread in association with sinks and as small structures observable only in the mines. Fault drag folds occur along the zones of faulting and most of them dip in a direction perpendicular to the strike of the faults.

The major structural features include folds, faults, and basement rock knobs and ridges. Although the latter are physiographic forms, they are considered major structural features because they are essential to the definite structural environment. The Farmington anticline is an open, doubly plunging fold about 20 miles long striking approximately N. 30° W. Seventy-nine igneous dikes and pipes, some of which have been called diatremes, are distributed over the southern nose of the anticline. The Ste. Genevieve fault zone strikes northwest, and 60 miles of its length is within the mining district. It contains both normal and reverse faulting developed during two distinct periods of movement. The early period, characterized by high angle tensional faulting, is post-Middle Devonian and pre-Mississippian; the late period of movement is considered post-Pennsylvanian in age, and it produced the reverse faults. The maximum stratigraphic displacement is about 1200 feet. The Simms Mountain fault zone, a zone of normal faulting, has been traced for 40 miles in a northwest direction. Near the southeast end it has an en echelon pattern that changes to a diverging pattern further southeastward. At several places the direction of dip of the beds adjacent to the faults is parallel to the strike of the faults, and this relationship indicates that a component of stress possibly acted parallel to the strike of this structure. The maximum stratigraphic displacement is about 600 feet.

The Palmer fault zone is 45 miles long in the area included in the accompanying maps and it has a general northwest trend. It is a zone of normal faulting characterized by several long narrow grabens in southern Washington County. The maximum stratigraphic displacement is more than 1200 feet. The Big River fault zone is the only major feature that deviates from the predominant northwest trend of the structural pattern. It is a zone of en echelon fault pattern trending northeast and is about 24 miles long. Sheet structure and fracture cleavage are evidence of tangential stress and the orientation of the fracture cleavage indicates that the northwest side has moved differentially northeastward.

Other zones of major faulting include the Wolf Creek-Greasy Creek zone, probably more than 20 miles long, with a maximum stratigraphic displacement of less than 200 feet; the Shirley zone, eight miles long, with a maximum displacement of about 350 feet; the Black zone, about nine miles long, with a maximum stratigraphic displacement of 300 feet; and the Berryman fault zone, about nine miles long, with a maximum displacement of 250 feet. If the Leasburg fault is continuous with the Berryman, the total length would be more than 40 miles.

The Flat River structural block is a compound feature bounded by zones of faulting on the north, northwest, southwest, and south, and by an anticline on the east. The sediments within the block dip southwestward, opposite to their direction of dip prior to deformation.

A structural environment is formed by either a single or a combination of structural features which were favorable for ore emplacement. Three of them have been recognized and each has associated with it a distinctive type of lead ore body. The fault zone structural environment is characterized by deformation consisting of an intricate pattern of many parallel, sub-parallel, and branching faults accompanied by a multitude of other fracture planes. The associated ore bodies in plan view have the long, narrow form common to vein deposits, but they have a restricted vertical dimension. Their stratigraphic distribution ranges from the Bonneterre to the Roubidoux, but most of the production came from deposits at or near the Potosi-Eminence contact. The ore bodies are along the faults in the bordering belt of intense fracturing, rarely in the zone of maximum displacement.

The knob and ridge structural environment is illustrated in the vicinity of Fredericktown, Madison County, where knobs and indefinite ridges of basement rock are surrounded by sediments which filled the valleys on the pre-Cambrian erosional surface. The local fracture system developed in the sediments adjacent to these physiographic forms influenced the position and shape of the ore bodies. The position of this type of lead ore body is coincident with the position of the local fracture system.

The structural block environment was produced in a section of the crust which was tilted upward on the east, upthrown by faulting on the north and northwest, and downthrown by faulting on the southwest and south. This deformation produced fractures and slippage in the sediments, and faults branching from the boundary zones of faulting extend into the structural block. Ore bodies associated with this environment are found only in the Bonneterre formation, and although their stratigraphic position is variable, the largest production has come from the lower half of the formation. The ore is distributed vertically through 200 or more feet in some stopes, but it is not uniform in tenor throughout this height. The ore bodies at the lower levels are the most persistent, and the mineralization is confined to a zone 20 to 30 feet thick and 20 to 50 feet above the base of the formation. More than one level is common and the ore bodies at the upper level are smallest.

The coincident positions of the mining district and the area of most intense deformation by faulting and the nearly universal association of faulting with epigenetic ore deposits is the basis for assuming that this structural deformation is one of the basic prerequisites for the location of the district. Some general geologic data aid in interpreting the structural history of the area. The regional structural trends have a northwest strike and they suggest the intensity of the applied stress, the magnitude of the area subjected to the stress, the medium through which the stress was transmitted, and that the stress was applied from either a northeast or southwest direction. The variation in intensity of crustal reaction with geographic locality is reflected by the structural features which show that the area of the mining district contains the most intense deformation associated with the structural apex of the Ozark uplift. The fault pattern consists of sub-parallel fault zones and a connecting cross fault zone. The reverse faulting aids in establishing the direction from which the deformation stress was applied, and it indicates that the stress was directed from the southwest toward the northeast. The thickness of the sedimentary veneer probably never exceeded 4000 feet, and it is likely that 3000 feet was a maximum thickness. The thin sedimentary cover would limit the capacity of the sediments to transmit stress and, therefore, the implication that the stress was transmitted in a large part through the basement rock is substantiated. The characteristics of sedimentation indicate that a positive highland existed at the approximate position of the St. Francois Mountains during the deposition of the Lamotte, and the Ozark uplift generally has maintained an elevated position throughout geologic time. The regional flexures are mostly broad and low and the absence of close folds is conspicuous. The joint systems at widely separated areas within the mining district have a parallel orientation.

The age of only some structural features can be determined accurately. The interrelation of several structures indicates the sequence of development, although their specific age is unknown. An attempt to decipher the structural history is hampered by the incomplete geologic record. After Middle Devonian, but before Mississippian time, magmatic pressure caused explosive blowouts through approximately 4000 feet of sediments. Upfolding and tensional faulting attended this period of deformation; the Farmington anticline originated and was broken axially at the north end by high angle faulting; Silurian and Devonian strata were downfaulted in the Ste. Genevieve fault zone. Collapse as a factor influencing the pattern of deformation cannot be ruled out, although its influence can be only speculative. The release of the magmatic force produced a low pressure chamber and a downward settling of the crust may have followed. The mining district was subjected to compressive stress in either late or post-Pennsylvanian time. The force was applied over a large area and propagated through the basement rock from a southwest direction. It produced reverse faulting in the Ste. Genevieve fault zone, the en echelon pattern in the Big River fault zone, and movement along the Berryman fault zone. Folds with their axes perpendicular to the Simms Mountain fault zone may be the result of this stress. The high angle faulting that cuts the north end of the Farmington anticline was subjected to movement opposite in direction to that which first produced it. Movement probably occurred in either late or post-Pennsylvanian time along all the fault zones in the area.

The thin sedimentary cover on the west flank of the Ozark uplift is in sharp contrast with the abrupt thickening of the sediments on the east flank where they reach a thickness of nearly 12,000 feet in the Central Illinois Basin. At the steep contact between the basement rock and the sediments the force transmitted from the southwest would be transferred from the basement rock to the thick sediments. The thick sediments could carry a greater proportion of stress and they would be influenced less by the strong basement rock than the thin sediments. The decreased influence of the basement rock and the greater stress transferred to the thick sediments could combine to produce the marked deformation by compressive stress northeast of the structural apex of the Ozark uplift.

Mining may be extended vertically and laterally. Any extension must involve the factors of a favorable host rock, the presence of mineralizing solutions, and favorable structural environments. The Bonneterre is the most favorable host rock and it underlies younger sediments at the surface except where it is overlapped because of hills on the basement rock surface. The writer knows of the presence of mineralizing solutions, indicated by ore minerals, in 11 townships totaling 396 square miles. The area enclosed by these occurrences includes about 1800 square miles, of which approximately 500 square miles have rocks older than the Bonneterre at the surface.

The structural history of the Flat River structural block apparently is not duplicated elsewhere in the district. The area that may contain the knob and ridge structural environment is estimated at 1500 square miles, or nearly half of the total area on the accompanying maps. The fault zone structural environment is associated with zones of faulting and it is doubtful if major faulting exists which has not been mapped either in detail or by reconnaissance survey.

The possibilities for lateral extension of mining are suggested by the size of the area that may contain ore bodies. Possibilities for vertical extension of mining, especially downward, are suggested by the sandy dolomite lenses in the Lamotte, some of which are mineralized and have been mined at two places. The stratigraphic and structural possibilities are exceedingly favorable for the future expansion of the mining district.

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